Cotton Catchment Communities CRC

FINAL REPORT

Part 1 - Summary Details

Cotton CRC Project Number: **1.1.17**

Project Title: Improving management of summer weeds in dryland cropping systems with cotton

Project Commencement Date: 01/07/05 **Project Completion Date:** 30/06/08

Cotton CRC Program: **The Farm**

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Part 3 – Final Report

Background

A one year scoping study (phase I) was commissioned to determine and prioritise the weed issues of cropping systems with dryland cotton in 2001. This was funded jointly by the Cotton CRC, CRDC, GRDC and Weeds CRC. The main findings were that the weed flora was diverse, cropping systems complex, and weeds had a major financial and economical impact. Many of the common weeds were not controlled adequately or consistently in all parts of the rotation. Weed control was highly reliant on glyphosate in fallows and on atrazine in sorghum, but a diverse range of herbicides and mixes were used in cotton. Few non-chemical control options were used, and residual weeds often resulted in significant replenishment of the seed bank. The report highlighted that fleabane was an emerging weed issue with the potential to become a major problem, which has eventuated since this study.

Research in phase II (2002/2005) focused on improved management of five key summer weeds, bladder ketmia, sowthistle, fleabane, barnyard grass and liverseed grass. The project was to strategically manage these weeds, with a particular emphasis on developing better control practices for the weak-links of the rotations, and reducing replenishment of the soil seed bank, which will reduce the economic impact of weeds in the long term. A national fleabane workshop was held to develop draft strategies for control. Since then a large effort into researching better management of fleabane was done in both crop and fallow.

Research in phase III (2005/2008) aimed to further develop improved management options for the problem weeds mentioned above, in particular fleabane and summer grasses, and modify these strategies to minimise risk of development of glyphosate resistant weeds. The project investigated options for better and more consistent control of problem weeds that integrate safe and effective use of residual and knockdown herbicides, strategic use of tillage and competitive crops, together with a better understanding of the weeds' ecology. A simple decision support tool, based on data generated, was investigated to predict the long-term impact of different management tools on the weed population in following crops.

The two research phases were jointly funded by the Cotton CRC, CRDC, Weeds CRC and GRDC.

These outputs will reduce the economic impact of weeds in the long-term, ensure sustainable use of glyphosate in the future, and enable growers to select the most effective weed management package for the weeds and rotations.

Objectives

The aim of this project (phase III) was to:

- improve weed control, particularly fleabane, and summer grasses, in different components of the cropping system with dryland cotton
- develop management strategies for the sustainable use of glyphosate
- develop a decision support tool to predict the impact of weed management strategies on the weed seed bank.

These aims were achieved by:

- Increased understanding of the dynamics of weed seeds in the soil seed bank
- Identification of strategies for improved control of fleabane
- Identification of strategies for improved control of summer grasses
- Developing strategies to minimise the risk of weeds developing glyphosate resistance in dryland cropping systems with glyphosate-tolerant cotton
- Developing a decision support tool to predict the impact of different management options on the weed seed bank.

Methods

<u>Dynamics of weed seeds in soil seed bank</u>

The 3 ground pot studies that were underway in the previous project (phase II) continued for an additional 2 years, and 3 new experiments were commenced. These contained barnyard grass, liverseed grass, sweet summer grass, bladder ketmia, fleabane and sowthistle buried at various depths in different soils and environments. Seeds were exhumed at specific intervals, and extracted seeds subjected to germination with tetrazolium tests in order to determine seed viability, dormancy and persistence. The impact of different tillage practices on emergence and persistence was also studied. These data were used to derive predictive relationships between weed emergence, seed persistence and important environmental factors.

<u>On-farm research to improve fleabane control</u>

Effectiveness of management options for improved fleabane control was investigated in 8 experiments in rotational crops and fallows prior to cotton and in cotton. These studies include fleabane in wheat, sorghum, cotton, and two field and one pot experiment examined the effectiveness of sequential knockdown herbicide applications, known as the "double knock" tactic, for its effectiveness on fleabane control.

On-farm studies to improve the control of summer grasses

Efficacy of atrazine for better grass and broadleaf weed control in sorghum was compared for different application times, with and without mechanical and rain incorporation. Ten atrazine based herbicide treatments were compared, including atrazine with and without metolachlor, pendamethalin and imazapic. The impact of residual herbicides on following dryland cotton was assessed by glasshouse bioassays, using intact soil cores collected from experimental plots, and with field re-cropping studies.

Strategies to minimise the risk of weeds developing glyphosate resistance

In the above experiments, glyphosate-based treatments were compared with alternatives for effectiveness in weed control in different components of the rotation. This information was used to develop options to minimise the risk of weeds developing glyphosate resistance in both conventional dryland cropping systems and those with glyphosate-tolerant cotton.

Predicting the impact of management options on weed seed bank and future weed problems

The team identified the Weeds CRC seed bank model "Weed Seed Wizard" as a suitable tool to predict the impact of different management options on weed populations in the grain and dryland cotton farming systems. Ecological and management data were collected from an additional 8 paddock monitoring sites and then incorporated into the model.

Results

Dynamics of weed seeds in the soil seed bank

The emergence and persistence of weed seed differed substantially between species in the sub-tropical cropping environment.

Barnyard grass

- Emerged in several flushes each year, pre-dominantly from the surface soil.
- Majority emerged in the first year after seeding, with only 5% emerging in following years.
- 5% of sown seed emerged from 5 cm depth and 1% from 10 cm depth.
- 2-5% persisted after two years at 2 cm depth, this increased to 9-28% and 24% for seed at 5 and 10 cm depth respectively.
- Tillage increased emergence and tended to decrease persistence.

Sweet summer grass (central Queensland)

- 39% seed emerged from 2 cm depth, 6-22% from 5 cm, and 1-2% from 10 cm depth over two years.
- There was a major flush in December in the first year, with a number of flushes in February in both years.
- After two years, no seed was viable at 2 cm depth, whereas 7 and 20% seed persisted at 5 and 10 cm depth respectively.

Liverseed grass

- Emerged mostly in one major flush.
- Emergence was greater from 5 cm than 2 cm depth, and 17% of seed were able to emerge from 10 cm.
- After two years of burial, 1% seed was viable at 2 cm depth, but 21% remained at the 10 cm depth, and this declined to 11% after three years of burial.

Bladder ketmia

- In central Queensland it emerged in four flushes from September to February.
- There was 8-39% emergence from 2 cm depth, 2-10% at 5 cm and<1-5% at 10 cm.
- After two years 11% seed persisted at 2 cm, and 21% at 10 cm, this declined to 11% after three years.
- In southern Queensland, emergence patterns differed with time.
- In the first 12 months, emergence was greater from 5 cm than 2 or 10 cm respectively.
- In the following year, 12% emerged from 2 cm and 6 and 0.5% from 5 and 10 cm respectively.
- After three years burial, 31% of buried seed persisted at 2 cm and 52% persisted at 10 cm depth.

Common sowthistle

- Only 4% of sown seed persisted after one year in the surface soil (0-2 cm).
- Seedlings emerged in a series of flushes all year round.
- No emergences occurred from depths greater than 2 cm.

Fleabane

- 6% of seed buried remained after 3 years burial, with least persistence in the surface soil and most at 10 cm depth.
- Emergences only occurred from the surface soil (0-2 cm) with no emergence from seeds buried a 5 or 10 cm depth.
- No emergences occurred in the self-mulching black vertisol soil.
- On farm monitoring data showed that fleabane emerged throughout autumn, winter and spring, with most emerging in late autumn, early and late winter, and only a small fraction emerged in mid spring.
- Emergence decreased with tillage, particularly for chisel plough and disc plough.

<u>Strategies for improved control of fleabane</u>

Substantial advances have been made in developing, delivering and the adoption of effective management strategies for fleabane. The successful strategy is based on a systems approach using a combination of herbicides and non-chemical options, together with effective timing of the tactics.

Control in wheat

- For heavily infested paddocks, an effective strategy is chlorsulfuron applied pre-plant in a competitive crop, with survivors controlled by 2, 4-D or picloram + MCPA.

Control in sorghum

- Control is best achieved prior to sowing sorghum, using an effective knockdown treatment followed by atrazine applied in late winter just prior to an imminent rainfall event.

Control in cotton

- Control is best achieved prior to sowing cotton, using an effective knockdown treatment.

Strategic tillage can reduce fleabane emergence

- Fleabane emergence occurred predominately in winter.
- Fleabane emergence was highest in no-till and light harrow treatments.
- Disc ploughing and cultivating were able to significantly reduce fleabane emergence by burying the seed to depths of greater than 1 cm, below which it could not emerge.

Double knock is effective for fleabane control

- In the first trial, the tolerance of fleabane to glyphosate was evident with only 55% control achieved in the glyphosate only treatment. Glyphosate followed by paraquat + diquat provided good control of plants. However as time between treatments increased, the level of control decreased. The addition of 2,4-D to glyphosate provided better control, but again increased intervals between sprays reduced the level of control. Glyphosate and 2,4-D followed by the higher rate of paraquat + diquat provided total control of plants in all cases. Paraquat + diquat proved to be an effective tool in a "double knock" strategy for fleabane control.
- The second trial with a denser population of fleabane also showed a poor result for control achieved with glyphosate alone. For the treatments containing 2,4-D, as the period between initial and follow-up applications increased, the level of control decreased. The combined glyphosate + 2,4-D treatment was marginally better than the split application of glyphosate and 2,4-D (containing the same rate of 2,4-D) on the same day and one day later. At longer intervals between glyphosate and 2,4-D applications (3 and 5 days) fleabane control was considerably poorer. Double knock using glyphosate followed by paraquat was also trialled. At the same rate, paraquat gave a higher level of control than paraquat + diquat in this trial. Timing of the follow-up application was also important for these herbicides. Highest control for these herbicides was achieved when they were applied at 5 and 7 days after glyphosate.

Previous herbicide exposure can affect tolerance to herbicide control

- A pot trial investigated the effectiveness of glyphosate and the double knock tactic on fleabane relative to previous exposure to herbicides. The first fleabane population came from beside a dam where no herbicides had previously been used. The second population came from a cropping field that had previous herbicide exposure.
- The population from the cropping area had a significantly greater tolerance to glyphosate when applied alone or as part of a double knock.

National workshop enhance knowledge of fleabane management

- A national workshop on fleabane was held in February 2007.
- Recent research findings of fleabane were presented since the 2004 workshop.
- Gaps in RD&E for fleabane management were identified and prioritised.
- Papers from the 19 presentations were compiled into the proceedings now available on the Weeds CRC website.

An updated strategy for fleabane management will be available on the Cotton CRC and DPI&F websites.

<u>Strategies for improved control of summer grasses and safe use of residual herbicides</u>

- Three experiments studied grass control options in sorghum and fallow, and five experiments measured the impact of residual herbicides on the following cotton crop under a variety of environments.
- Residual grass and broadleaf weed control was excellent with atrazine pre-plant and at-planting treatments, provided that rain was received within a short interval after application.
- Best treatments for sweet summer grass control in the fallow were the double knock (combinations of glyphosate, paraquat and tillage), imazapic, high rate pendimethalin, and the early rod weeding tillage.
- Where fallow weed control was >90%, coupled with excellent fallow seed-set reduction (double knock and early tillage treatments), in-crop grass control was dramatically improved and seed-set was also much reduced.
- Stopping seed-set during the fallow greatly reduced the in-crop recruitment. Some of the treatments that were less effective during the fallow, such as the residual herbicides (atrazine, imazapic and pendimethalin) when applied to emerged weeds, were more effective in the in-crop phase by reducing in-crop grass recruitment.
- In the 5 re-cropping experiments, there were no adverse impacts on cotton from atrazine, metolachlor, metsulfuron and chlorsulfuron residues following use in previous sorghum, wheat and fallows.
- However, imazapic residues did reduce cotton growth with 50-70% biomass reduction respectively. However after 150 mm in-crop rain, the cotton fully recovered from this early injury.

- The project team published a 6-page brochure on management of barnyard grass and liverseed grass, which is now available on the Cotton CRC, DPI&F and Weeds CRC websites.

Strategies to minimise the risk of weeds developing glyphosate resistance in dryland cropping systems with glyphosate-tolerant cotton

- The double knock tactic was compared to glyphosate alone treatments for its effect on fleabane and grass control.
- Double knock was considerably more effective on fleabane and grass control than glyphosate alone.
- This tool will be very important, not in controlling fleabane and grasses, but preventing the development of glyphosate resistance.
- The experiment investigating the effect of strategic tillage on fleabane emergence showed that disc ploughing and cultivation can bury the fleabane seed below its optimum emergence depth, limiting future emergence and therefore reliance on glyphosate for control of this weed in fallow.
- Steve Walker contributed to the national Glyphosate Sustainable Working Group, which met annually in Adelaide

New decision support tool to predict the impact of different management options on weed seed bank

- The team identified the Weeds CRC seed bank model "Weed Seed Wizard" as a suitable tool to predict the impact of different management options on weed populations in the grain and dryland cotton farming systems.
- 6 monitoring sites were set up in southern Queensland in conjunction with this project to gather data on the seed bank dynamics of fleabane, barnyard grass, sowthistle and wild oats, which were used to parameterise the model
- In central Queensland the seed bank dynamics of sweet summer grass was studied in a replicated rotational experiment, which examined the impact of two district practices in fallow, sorghum and sunflower.

A TECHNICAL REPORT OUTLINING MORE DETAILED RESEARCH RESULTS WILL BE SUBMITTED TO THE FUNDING BODIES.

Outcomes

This project has shown that the economic impact of difficult-to-control weeds can be reduced by adopting an integrated approach to weed management. This approach includes using tillage to bury seed below its optimum emergence depth with the aim to minimise future emergences. In addition, management strategies targeted to key weed species in each paddock using knockdown and residual herbicides can provide effective weed control, limit seed production of weeds and reduce subsequent problems. Using the double knock tactic for fleabane with the aim to

achieve improved control and prevent seed production is very important in the management of this species.

Glyphosate is an important herbicide and its future is threatened due to the evolution of glyphosate resistant weeds and species shifts. This project investigated strategies to prolong its effectiveness and minimise the risk of glyphosate resistance evolution in farming systems with dryland cotton. These include strategic tillage and rotating herbicide mode of action groups. Particular focus has been applied to the double knock tactic for its effectiveness in comparison to glyphosate only treatments. This tactic is highly effective in the prevention and management of glyphosate resistance.

The 'Weed Seed Wizard' is a tool that will enable growers to select the most effective weed management treatments for their weeds and rotations. The prototype uses current knowledge of weed biology and the effectiveness of management techniques to simulate and predict future changes in annual weed populations and seed bank dynamics.

- Technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.); not applicable
- Other information developed from research (eg discoveries in methodology, equipment design, etc.); not applicable
- Required changes to the Intellectual Property register; not applicable

Conclusion

1. The emergence patterns and persistence of weed seeds varied with species and also environment. Some species in particular small seeded ones, such as fleabane, sowthistle, barnyard grass and to a lesser extent sweet summer grass, mainly emerged from the surface, whereas other larger seeded species, liverseed grass and bladder ketmia can emerge from depth. The persistence of weed seeds increased with burial depth. Therefore, weed management plans need to be tailored for each main weed species. While tillage is a useful tool for burying seed to prevent emergence, it should be noted that the persistence of these seeds increases, and they should be left buried for long enough for the viability of these seeds to decline. The information added into the "Weed Seed Wizard" contains this important information and will help in the successful management of these weeds.

2. Fleabane is a weed that is still hard-to-control, but it can be effectively managed with a pro-active and strategic approach. Our research has shown that using strategic tillage to bury the seed will limit emergence and reduce reliance on herbicides for control. Double knock has proved a highly effective tactic for fleabane control. However, herbicide rates need to be robust for maximum effectiveness, and the timing of the second knock is important.

This tactic can provide 100% control and prevent seed set, which is critical to the management of this weed. Management in the fallow is the key to prevent infestations in summer crops.

3. Double knock is also effective for the control of sweet summer grass and also stopped seed set production. Stopping seed set in fallow was also important for minimising in-crop recruitment.

4. When using atrazine and imazapic for controlling summer grasses, it is important to consider effects on following crops such as cotton. Our research showed that lower rates of atrazine applied in sorghum prior to cotton did not effect cotton emergence, however imazapic did.

5. Glyphosate is an important herbicide for weed management. This project investigated ways in which to prolong its effectiveness. Combining glyphosate with other herbicides such as paraquat, paraquat + diquat and 2, 4-D in the form of the double knock tactic was able to provide additional control and prevent seed set in key weed species. Other weed management tactics, such as strategic tillage and residual herbicides, also help to reduce the reliance on glyphosate. These tactics used in an integrated weed management system will minimise the risk of glyphosate resistance development, and aid in the control of hard to control weeds such as fleabane.

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

Several new research projects have been funded that will use this project technology to further improve weed management in grain and cotton systems and reduce the risk for development of glyphosate resistance.

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

- A management guide is currently being updated for fleabane. This will be located on the Cotton CRC and DPI&F websites, with additions for Weedpak planned.
- A presentation will be made to the Australian Cotton Conference.
- Four papers are scheduled this year for submission to scientific journals.
- Discussions and plans are underway with the cotton crop protection extension team to extend these research outputs.

(c) for future research

Research to date has gained important information on the management of difficult-to-control weeds, in particular fleabane. Further investigation on applying the double knock with other knockdown herbicides, and in particular combining the follow-up knockdown herbicide with residual herbicides to minimise subsequent emergences is warranted. Fleabane is also spread easily by wind, and management of non-crop areas is an issue that needs to be investigated. With the rising price of glyphosate and the introduction of glufosinate tolerant cotton, the ability of

glufosinate to control fleabane and other difficult-to-control weeds should be investigated, along with its usefulness in a double knock situation. GRDC, Cotton CRC, CRDC and Monsanto have agreed to fund 3 new research projects on herbicide resistance in grain and cotton systems and management of fleabane.

Publications

Refereed journals

Wu H, Walker S, Rollin M, Tan D and Werth J (2007) Germination, persistence and emergence of flaxleaf fleabane (*Conyza bonariensis* [L.] Cronquist). Weed Biology and Management 7, 192-199.

Werth J, Preston C, Taylor I, Charles G, Roberts G and Baker J (2008) Managing the risk of glyphosate resistance in Australian glyphosate-resistant cotton production systems. Pest Management Science 64, 417-421.

Werth J, Preston C, Roberts G and Taylor I (2008) Weed management impacts on the population dynamics of *Echinochloa crus-galli* in glyphosate resistant cotton (*Gossypium hirsutum*) in Australia. Weed Technology 22, 190-194.

Papers in preparation

Wu H, Walker S, Taylor I and Robinson G (2008) Improving sorghum competitiveness on weed suppression via manipulation of cultivar and seeding rate. (Proposed journal *Weed Science*).

Osten I, Wu H and Walker S (2009) Weed seed production is massive under wide-row sorghum in the absence of herbicides. (Proposed journal *Australian Journal of Agricultural Research*).

Walker S, Wu H, Burrell D (2008) Emergence and persistence of *Echinochloa colona*, *Urochloa panicoides* and *Hibiscus trionum* in the subtropical environment of north-east Australia. (Proposed journal *Weed Research*).

Werth J, Walker S, Boucher L and Robinson G (2009) Applying the double knock technique to control flaxleaf fleabane (*Conyza bonariensis*). (Proposed journal *Weed Technology*).

Conference papers

Walker S and Robinson G (2008) Flaxleaf fleabane – the next glyphosate resistant weed. Proceedings 16th Australian Weeds Conference, Cairns.

Werth J, Widderick M, Osten V and Walker S (2008) Improving glyphosate efficacy on difficult to control summer weeds. Proceedings 16th Australian Weeds Conference, Cairns.

Wu H, Walker S, Osten V and Robinson G (2008) Competitive ability of some sorghum cultivars and densities on weed suppression. Proceedings 16th Australian Weeds Conference, Cairns.

Osten V, Wu H, Walker S, Wright G and Shields A (2006) Weeds and summer crop row spacing studies in Queensland. Proceedings 15th Australian Weeds Conference, Adelaide.

Walker S, Wilson B, Wu H, Widderick M and Taylor I (2006) Weed seed persistence with changing farming practices in southern Queensland. Proceedings 15th Australian Weeds Conference, Adelaide.

Wu H, Walker S, Taylor I, and Robinson G (2006) Biology and management of flaxleaf fleabane. Proceedings 15th Australian Weeds Conference, Adelaide.

Walker S, Wu H, Osten V, Widderick M, and Taylor I (2006) Managing difficult to control weeds in dryland systems. Proceedings 13th Australian Cotton Conference, Gold Coast.

Grower magazines and articles

Wild K and Osten V (2008) Fleabane could become the bane of farming. Cropping Central Issue 38 (March).

Walker S, Widderick M, Thornby D, Werth J, Osten V (2007) Management of barnyardgrass and liverseed grass. http://www.weeds.crc.org.au/documents/fs70_barnyard%20and%20liverseed%20grass.pdf

Werth J, Widderick M and Walker S (2007) Double knock – a winner for summer weed control. Future Grain magazine.

Wu H and Walker S (2006) Managing flaxleaf fleabane, a difficult-to-control weed in dryland cropping systems associated with zero tillage. www.dpi.qld.gov.au/fieldcrops

Walker S and Wu H (July-August 2006) Knocking out flaxleaf fleabane. Australian Grain.

Walker S & Wu H (Mar 2006) Managing fleabane in wheat. GRDC Grains Research Update Seminar, Goondiwindi.

Walker S (2006) Fleabane weed in spotlight. Queensland Country Life. 7th September, 2006.

Walker S (March 2007) The (flea)bane of reduced tillage systems. GRDC Crop Doctor. www.grdc.com.au/growers/cd/north/northern_region07001.htm

Walker S (Nov-Dec 2006) The (flea)bane of reduced tillage systems. Australian Grain.

Walker S and Somervaille A (2006) Fleabane – hard to kill but a poor competitor. In GRDC Update Newsletter.

Weeds CRC project web page (completed and online) http://www.weedscrc.org.au/projects/project_2_2_2_2.html

Seminars, workshop and grower meetings

Werth J (2008) Controlling fleabane using the double knock tactic. GRDC Grain Research Update Seminar, Goondiwindi.

Werth J, Thornby D, Widderick M, Walker S (2008) Double knock and the potential for glyphosate resistance in barnyard grass. GRDC Grain Research Update Seminar, Roma.

Walker S, Werth J, Widderick M (2007) Proceedings of Fleabane Workshop. http://www.weeds.crc.org.au/publications/wshop_proceedings.html

Walker S, Wilson B, Wu H, Widderick M, Taylor I (Feb 2007) Seed persistence of key northern weeds. GRDC Grains Research Update Seminar, Dubbo.
Walker S, Wilson B, Wu H, Widderick M, Taylor I (Mar 2007) Seed persistence of key northern weeds. GRDC Grains Research Update Seminar, Goondiwindi.
Werth J (August and November 2007) Biology and management of flaxleaf fleabane. IWM Worshop for agronomists, Toowoomba.
Walker S and Werth J (March 2007) Double knockdown control on fleabane. CRT workshop, Toowoomba.
Werth J (March 2007) Managing the risk of glyphosate resistance in Australian glyphosate-resistant cotton production systems. International symposium on 'Glyphosate-resistant crops and weeds: Present and Future' Chicago USA.
Walker S (July 2007) GRDC Update Seminars, Moree and Spring Ridge
Walker S (November 2006) National IWM workshop for senior advisers.

Part 4 – Final Report Executive Summary

In 2001 a scoping study (phase I) was commissioned to determine and prioritise the weed issues of cropping systems with dryland cotton. The main findings were that the weed flora was diverse, cropping systems complex, and weeds had a major financial and economical impact. Phase II 'Best weed management strategies for dryland cropping systems with cotton' focused on improved management of the key weeds, bladder ketmia, sowthistle, fleabane, barnyard grass and liverseed grass.

In Phase III 'Improving management of summer weeds in dryland cropping systems with cotton', more information on the seed-bank dynamics of key weeds was gained in six pot and field studies. The studies found that these characteristics differed between species, and even climate in the case of bladder ketmia. Species such as sowthistle, fleabane and barnyard grass emerged predominately from the surface soil. Sweet summer grass was also in this category but also had a significant proportion emerging from 5 cm depth. Bladder ketmia in central Queensland emerged mainly from the top 2 cm, whereas in southern Queensland it emerged mainly from 5 cm. Liverseed grass had its highest emergence from 5 cm below the surface. In all cases the persistence of seed increased with increasing soil depth. Fleabane was also found to be sensitive to soil type with no seedlings emerging in the self-mulching black vertisol soil. A strategic tillage trial showed that burial of fleabane seed, using a disc or chisel plough, to a depth of greater than 2 cm can significantly reduce subsequent fleabane emergence. In contrast, tillage increased barnyard grass emergence and tended to decrease persistence. This research showed that weed management plans can not be blanketed across all weed species, rather they need to be targeted for each main weed species.

This project has also resulted in an increased knowledge of how to manage fleabane from the eight experiments; one in wheat, two in sorghum, one in cotton and three in fallow on double knock. For summer crops, the best option is to apply a highly effective fallow treatment prior to sowing the crops. For winter crops, the strategy is

the integration of competitive crops, residual herbicide followed by a knockdown to control survivors. This project explored further the usefulness of the double knock tactic for weed control and preventing seed set. Two field and one pot experiments have shown that this tactic was highly effective for fleabane control. Paraquat products provided good control when followed by glyphosate. When 2, 4-D was added in a tank mix with glyphosate and followed by paraquat products, 99-100% control was achieved in all cases. The ideal follow-up times for paraquat products after glyphosate were 5-7 days. The preferred follow-up times for 2, 4-D after glyphosate were on the same day and one day later. The pot trial, which compared a population from a cropping field with previous glyphosate exposure and a population from a non-cropping area with no previous glyphosate herbicide exposure, showed that the pervious herbicide exposure affected the response of fleabane to herbicidal control measures. The web-based brochure on managing fleabane has been updated.

Knowledge on management of summer grasses and safe use of residual herbicides was derived from eight field and pot experiments. Residual grass and broadleaf weed control was excellent with atrazine pre-plant and at-planting treatments, provided rain was received within a short interval after application. Highly effective fallow treatments (cultivation and double knock), not only gave excellent grass control in the fallow, also gave very good control in the following cotton. In the five re-cropping experiments, there were no adverse impacts on cotton from atrazine, metolachlor, metsulfuron and chlorsulfuron residues following use in previous sorghum, wheat and fallows. However, imazapic residues did reduce cotton growth.

The development of strategies to reduce the heavy reliance on glyphosate in our cropping systems, and therefore minimise the risk of glyphosate resistance development, was a key factor in the research undertaken. This work included identifying suitable tactics for summer grass control, such as double knock with glyphosate followed by paraquat and tillage. Research on fleabane also concentrated on minimising emergence through tillage, and applying the double knock tactic. Our studies have shown that these strategies can be used to prevent seed set with the goal of driving down the seed bank. Utilisation of the strategies will also reduce the reliance on glyphosate, and therefore reduce the risk of glyphosate resistance developing in our cropping systems.

Information from this research, including ecological and management data were collected from an additional eight paddock monitoring sites, was also incorporated into the Weeds CRC seed bank model "Weed Seed Wizard", which will be able to predict the impact of different management options on weed populations in cotton and grain farming systems.

Extensive communication activities were undertaken throughout this project to ensure adoption of the new strategies for improved weed management and reduced risk for glyphosate resistance.