Positioning the second 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. bifurx) and the vines (Ipomoea londophylla 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 Roundup Ready 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® 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 much poorer efficacy on the grasses. It is weakly translocated and has no efficacy on the nutgrass, 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.
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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.

**ACKNOWLEDGMENTS**
We greatly acknowledge the support of the Cotton Research and Development Corporation.

**REFERENCES**