Herbicide Tolerant Cotton – It's Role in Sustainable Farming Systems

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Abstract

Many of Australia's broadacre crops have or will have herbicide tolerance traits added in the future. Cotton, canola, clover and wheat are just a few of the crops that are either being conventionally bred or genetically modified to tolerate both new and old herbicides. Cotton currently has Roundup Ready® technology with the possibility of other herbicide traits being introduced in the future, however, we need to mindful of the entire farming system and other rotation crops with similar traits being introduced. This is an important period where researchers, regulators, utilisers of the technology and consumers must communicate with each other in a timely manner where and how this technology should be utilised. In the case of cotton there are a large number of potential advantages but an equally large number of management considerations including, herbicide resistance, management of volunteers and herbicide application issues. This presentation attempts to cover some of the important considerations for cotton growers utilising herbicide tolerant cotton.

Introduction

In many broadacre crops, weeds are the most economically damaging pest. The improved ability to control weeds is usually rapidly adopted by farmers and as such herbicide tolerant crops are likely to dominate farming fields in the future. The term 'herbicide tolerant crop' is unusual, as many crops are already tolerant of a range of herbicides e.g. wheat is already tolerant of diclofop-methyl (Hoegrass®). The way the term is used though, generally refers to imparting herbicide tolerance to normally herbicide-susceptible crops such that they resistant to that particular herbicide. The methods of achieving this vary, but can include, conventional breeding and other techniques (e.g. triazine tolerant canola) or genes transferred through genetic manipulation (e.g. glyphosate tolerant canola).

The limited commercial release of glyphosate tolerant cotton (Roundup Ready® cotton) in the 2000/2001 growing season was the beginning of a new era in weed management for cotton. Although not revolutionary in solving weed problems, Roundup Ready® cotton (RR cotton) is the first commercial example in Australia of re-engineering old herbicide chemistry in new ways. The ability to take herbicides that would otherwise have killed cotton and apply them safely over-the-top is a dramatic departure from the usual 'new herbicide discovery' pathway that herbicide companies have previously embarked on. This approach has occurred for two reasons. First the ability to harness plant biotechnology and use molecular techniques that allow the insertion of unrelated genes into a plant that impart herbicide tolerance has finally reached commercial reality. Secondly, the declining discovery rate of new herbicides with different target sites and modes of action and the huge costs associated with screening a vast number of new molecules has increased the incentive to look at new ways of exploiting existing products. Further insights into why herbicide tolerant crops are being developed is provided by Duke (1996).

The focus of this paper is to cover some important considerations for the cotton industry when growing herbicide tolerant cotton.

What types of herbicide tolerant crops are being developed?

Triazine tolerant canola was the first broadacare crop with herbicide tolerance to be commercially introduced into Australia. This initial introduction went largely unnoticed because conventional breeding techniques were used to generate the tolerance. Since then imidazolinone tolerant canola has been released and the potential to release glyphosate and hybrid glufosinate-ammonium tolerant canola is being canvassed. The importance of these releases is that one crop will have tolerance traits to four different classes of herbicides.

Table 1 Herbicide tolerant crops and pastures (both conventional and genetically modified) developed for broadacre agricultural use. (Note: Some of these traits will/have not been taken to commercial production)

Crop	Herbicide trait
Canola	Bromoxynil, Glufosinate-ammonium, Glyphosate
Clover	Bromoxynil,
Corn	Glufosinate-ammonium, Glyphosate, Imidazolinones, Sethoxydim
Cotton	Bromoxynil, Glufosinate-ammonium, Glyphosate, Sulfonylureas
Lupin	Glufosinate-ammonium
Medic	Sulfonylureas
Rice	Glufosinate-ammonium
Soybean	Glufosinate-ammonium, Glyphosate, Sulfonylureas
Sugar Beet	Glufosinate-ammonium, Glyphosate
Tobacco	Bromoxynil
Wheat	Glyphosate, Imidazolinones

(Adapted from: Herbicide handbook, Weed Science Society of America, supplement to 7th edition 1998.)

Examining Table 1 it can been seen that many crops and pastures with herbicide tolerance have the potential to be released in the future and it is important that the regulatory authorities and proponents of the technology take an overall view of the cropping systems. This will ensure that the most useful traits are put in the crops that require them the most. With well developed plans the release of multiple traits into a range of crops offers the potential to enhance weed control without creating a range of volunteer weeds that are difficult to control. Cotton is already at the forefront of this technology with glyphosate tolerance and the potential commercialisation of glufosinate-ammonium in the future. Table 2 lists the herbicide traits that have been examined for cotton in Australia. In reality Roundup Ready® will be the only trait available for the next few years and as such optimizing the management of this technology should be the major focus of growers.

Table 2 Herbicide tolerant genes evaluated for cotton and potential commercial release dates in Australia. (Note: due to regular commercial company ownership changes, it is unclear as to which genes and release dates will proceed. All releases are subject to regulatory approvals.)

Herbicide Gene	Tolerance to Active	Introduction in Australia
Roundup Ready®	Glyphosate	2000
New Roundup Ready®	Glyphosate	2007 ?
Liberty Link®	Glufosinate-ammonium	2007 ?
Oxygene®	Bromoxynil/Ioxynil	Cancelled
2,4-D	2,4-D	On hold

It is important to look at the introduction of new herbicide tolerant genes in the context of the whole Australian cotton farming system. The immanent release of Bollgard II (2 Bt genes), and its likely high adoption rate, will mean that herbicide tolerant genes will need to be stacked with some form of insecticidal gene(s). While the technology to provide multiple trait stacks exists, and Bollgard II/Roundup Ready® combinations will be available, problems can exist if different traits are not all owned by the same company. Hence if controlling insects are still the main focus of cotton growers then it is likely that verities with herbicides tolerance genes alone will have only a small niche.

There are some potential advantages of having more than one herbicide tolerant gene available for cotton, particularly if they are herbicides with different modes of action. These advantages include the ability to target different weeds more effectively with different modes of action and the rotation of herbicide chemistry to help prevent herbicide resistance. The chances of obtaining resistance to two low risk herbicide groups such as glyphosate and glufosinate-ammonium in the same species is extremely low. Stacking the genes together in the same plant could allow a 'double knock' strategy in the same year. Modeling of southern Australian weeds (i.e. ryegrass) has shown that utilizing two herbicides with different modes of action that are both effective against the weed can be a very effective method of limiting herbicide resistance.

Considerations for Roundup Ready® In the Farming System

Table 3 Potential weed management strategies utilizing Roundup Ready® technology in Low and High weed density situations.

	Expected Weed Density			
	Low		High	
Timing of Operations	**Action**	**Potential Risks**	**Action**	**Potential Risks**
Pre - Plant	No pre – emergent herbicides	Unlikely	Apply residual herbicides	Herbicides damage crop/slow growth
Planting	No planting herbicides	Weeds emerge with crop	Apply residual herbicides	Herbicides damage crop/slow growth
Emergence to 4 true leaf	1st over-the-top with Roundup Ready	Can't apply Roundup Ready due to weather	1st (and 2nd) over-the-top with Roundup Ready	Can't apply Roundup Ready due to weather
4 leaf onwards	1st Shielded Roundup Ready	Slight potential for crop damage with drift	1st Shielded Roundup Ready	Slight potential for crop damage with drift
Prior to flowering	2nd Shielded Roundup Ready	High potential for crop damage with drift	Potential for 2nd shield of Roundup Ready	High potential for crop damage with drift
Prior to canopy closure			Directed Layby application of residual herbicide	Potential crop damage from drift
Prior to cutout	Spot Chip	Stop weed setting seed	Spot Chip	Stop weed setting seed

Table 4 Theoretical costs/ha of weed control systems for Low and High weed density situations.

	Weed density				
	Low		High		
	Cost	**Weed control**	**Cost**	**Weed control**	**Herbicide resistance potential**
Roundup Ready®	$73/ha	Good	$86/ha	Poor	High
Roundup Ready® + Full residual herbicides	$205/ha	Good	$219/ha	Medium - Good	Medium
Roundup Ready® + Full residual herbicides + Non chemical methods	$245/ha	Excellent	$259/ha	Good - Excellent	Low
Roundup Ready + Non chemical methods	$113/ha	Good	$166/ha	Medium	Low
Full residual herbicides + Non chemical methods	$170/ha	Good	$210/ha	Medium	Low

Assumptions = Low weed density situations require two Roundup Ready® herbicide applications. High weed density requires three Roundup Ready® herbicide applications. Non chemical methods of control include cultivation and chipping which are doubled in the high weed density situation.

Roundup Ready® cotton technology should not be seen as a stand alone tool in controlling weeds. In every situation that Roundup Ready® cotton is used it should used as part of an Integrated Weed Management (IWM) program. For more information on IWM see Taylor and Charles 2002, this proceedings and WeedPAK. The most important consideration in deciding how to use Roundup Ready® cotton is to estimate the likely weed type and density in each field. This will determine how many residual herbicides can be removed from the system. Table 3 provides some suggested weed management strategies for Low and High weed density situations. In Low weed density situations the Roundup Ready® technology acts as an insurance, providing effective post-emergent options should a small number of weeds be present. In High weed density situations the Roundup Ready technology should be used as an extra method of weed control – not the frontline strategy. This will ensure overall weed management is improved and not compromised.

The economics of Roundup Ready® are totally dependant on weed type and density in each field. Coupled with this is the amount of risk each grower is prepared to accept. In low weed density situations Roundup Ready® only situations can be very cost effective, however the chance of obtaining a glyphosate resistant weed can be high. Utilizing IWM, particularly non-chemical control methods, increases the costs but reduces the risk of resistance and species shift greatly. In high weed density situations the Roundup Ready® technology adds to the cost but can also improve the overall weed management result. Quality of weed control should always be taken into account when comparing herbicide tolerant crop strategies against conventional systems.

An additional management situation with herbicide tolerant crops is the control of volunteers in the following year. Cultivation and herbicides are the two most common methods of volunteer cotton control. Both require the cotton plants to have germinated and emerged before control can occur. This is particularly important if the volunteer plants being controlled have the Roundup Ready® gene and the following crop is cotton. The use of glyphosate will not control these seedlings. Cultivation will remove the in-furrow volunteers but miss the volunteers situated in the plant line. Rainfall or pre-irrigation is required to germinate these volunteer plants prior to planting, after which effective control can be attempted.

Broadacre cultivation will readily control seedling volunteers in most soil conditions, as the root system and hypocotyl of seedling cotton are easily destroyed by the cultivation process. Any damage that occurs below the cotyledons will kill the plant, as there are no growing points from which the plant can recover. Effective cultivation will only occur if the cultivation implement cultivates both the furrow and hill avoiding strips being left uncultivated. Cultivation will also manage other weeds besides seedling volunteer cotton. The disadvantage of cultivation is that it only controls established seedlings, is slow and can cause moisture loss or soil damage if conducted at the wrong time. In addition, volunteer establishment will mainly occur in periods very close to planting, which is an inappropriate time to be conducting large scale tillage operations. Never-the-less, cultivation is a valuable integrated weed management tool and should always be considered.

Herbicide control of Roundup Ready® seedling cotton

Table 5. provides a list of herbicides that were screened for efficacy against seedling volunteers. These herbicides were selected on their likely efficacy of controlling seedling

cotton with minimal residual carryover to either cotton or rotation crops. Glyphosate and mixtures that utilised glyphosate as the main active ingredient were excluded from testing so that results could be inferred for Roundup Ready® volunteers as well.

The results of this experiment suggest that Spray.Seed®, Hammer® and bromoxynil would be effective in controlling seedling cotton (including Roundup Ready® volunteers) at both 4 and 8 leaf growth stages. Surpass™, Basta®, Starane® and MCPA Amine are also options but are likely to be less reliable. In addition (excluding Basta®), there are spray management considerations with these herbicides, including drift and plant-back times to cotton. The results outlined are preliminary and no attempt was made to ascertain the most appropriate herbicide rate or the effects of combinations of herbicides. The results reported here are NOT recommendations.

Both Spray.Seed® and Hammer® are contact herbicides, with no residual carryover and their use patterns have been designed as pre-emergent crop knockdowns. The active components of Spray.Seed® (paraquat and diquat) are from the bipyridyl group of herbicides which inhibit photosynthesis at photosystem I (group L). Hammer® (carfentrazone) is a member of the aryl triazoline group which inhibits protoporphyrinogen oxidase (group G). The differences in modes of action from glyphosate, which inhibits EPSP synthase (group M) are important, as they allow these herbicides to control glyphosate tolerant cotton and also control other weeds using a different herbicide group. Rotating herbicide chemistry is an important component of preventing herbicide resistance. Hammer® can also be mixed with glyphosate or Spray.Seed®, improving the weed spectrum it controls. In theory, a mixture of Hammer® (at an adequate rate) and glyphosate would control Roundup Ready® seedling volunteers, as well as the usual weeds glyphosate is targeted against. With all contact herbicides, excellent spray coverage is essential for adequate control. This often means high (e.g. 100L/ha) water volumes per hectare.

Conclusions

The only commercial herbicide tolerant gene for cotton, at least to 2007, will be Roundup Ready®. Future genes, to be commercially feasible, will probably need to be stacked with an effective *Helicoverpa* controlling gene. The number of herbicide tolerant crops within the farming system is likely to increase and as such growers will have to carefully rotate the herbicide chemistry to delay herbicide resistance and more importantly, manage herbicide tolerant volunteers. Weed type and density should be the main consideration when considering the economics of Roundup Ready® technology. Herbicide tolerant crops should form one part of an Integrated Weed Management strategy.

References

Duke, S.O. (1996). Herbicide-resistant crops-background and perspectives. In: *Herbicide-Resistant Crops*. Ed. S.O. Duke. Lewis publishers, USA. pp. 1-10.

Table 5 Effect of herbicides on seedling cotton at St George (4 true leaves) and Narrabri (8 true leaves) in 2001-02. Labels in *italics* are tentative classes.

Herbicide	Trade Name	Rate/ha (kg or L/ha)	Active Ingredient (g/ha)	Percentage Control	
				St George 4 true leaves	Narrabri 8 true leaves
Unsprayed	-	-	-	0	0
Effective control					
Bromoxynil	Buctril 200	4	800	100	100
Carfentrazone	Hammer 240 EC	0.15	36	100	100
Paraquat+Diquat	Sprayseed 250	2	270+230	100	100
Incomplete control					
2,4-D Amine	Surpass	2	450	0	95
Glufosinate-ammonium	Basta	3	600	92	96
Fluroxypyr	Starane 200	1	200	25	95
MCPA Amine	MCPA 500	2	1000	30	88
No control					
Clopyralid	Lontrel	0.15	45	0	0
Dicamba	Banvel 200	1.4	280	2	0
Diuron	Diuron DF	1.9	1710	0	0
Fluometuron	Nu-Tron 900 DF	1.9	1710	0	0
Oxyfluorfen	Goal CT	0.25	60	15	0
Prometryn	Gesagard 500 SC	3	1500	19	10
Triclopyr	Garlon	0.15	90	0	0
			CV %	19.5	10.7