Changes in weeds and practices since the introduction of herbicide tolerant cotton in Australia

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Summary

The widespread adoption of glyphosate tolerant cotton in the last 10 years has substantially modified the weed control practices used in irrigated and dryland cotton crops. Data on changes in the weed populations, infestation levels and flora, and control tactics were compiled from field and industry surveys to compare changes in the weeds and practices used since the introduction of herbicide tolerant cotton. The focus was on three regions: Darling Downs with 36% dryland cotton grown, Gwydir (12%) and Lower Namoi (9%). Across the crop rotations, flaxleaf fleabane had increased dramatically in both dryland and irrigated systems, and there were more residual weeds in dryland than irrigated systems, particularly for bladder ketmia, flaxleaf fleabane, sowthistle and barnyard grass. The main weeds surviving within glyphosate tolerant crops, prior to implementation of remedial actions, were cow vine, flaxleaf fleabane, nut grass, bladder ketmia and barnyard grass, although relative importance differed between the regions. The approach to weed control over the last decade moved from pre-emptive use of residual pre-emergent herbicides to tactics for control of weed seedlings and survivors of glyphosate applications. Weed management practices were similar across the regions but differed somewhat between dryland and irrigated crops. The weed flora shift, threat of glyphosate resistant weeds, and the extent of weeds surviving in the other components of the rotation indicate the need for a more strategic approach to weed management to be applied across the whole cropping system.

Background

Glyphosate tolerant cotton has been adopted rapidly by the Australian cotton industry since its introduction approximately 10 years ago and currently accounts for nearly all of the crops sown. As a condition of using this technology, growers are obliged to implement the Crop Management Plan to ensure best use of the technology and minimise any potential adverse impacts. The main reasons for this major change is that it allows use of conservation tillage practices, controls a broad spectrum of weeds, and reduces the need to use residual herbicides, some of which can damage cotton seedlings (Werth et al. 2006). Recently, glufosinate tolerant cotton was also released, allowing use of an alternate knockdown herbicide in the crop. This paper reviews the changes in weed flora and practices used associated with herbicide tolerant cotton, particularly glyphosate tolerant cotton, and discusses the emerging or potential issues resulting from reliance on glyphosate in this cropping system.

Collation of data

The areas of dryland and irrigated cotton production for the three production areas were sourced from Cotton Yearbook, published by The Australian Cottongrower, for each year from 2000 to 2009.

A number of weed surveys have been conducted within the cotton growing regions. Charles et al. (2004) surveyed weed infestations and weed control practices from 19 irrigated properties in the Gwydir and Macintyre regions in 1992, 1996 and 2001 by which time 25% of the growers were using glyphosate tolerant cotton. Similarly, Walker et al. (2005) surveyed weed infestations and practices used in 32 paddocks in dryland cotton farms on the Darling Downs and Macintyre region in 2001. Conventional cotton was still grown on these farms at the time of the survey. In 2003 Werth et al. (2006) compared weed management practices used by 40 growers of both conventional and glyphosate-tolerant cotton. In 2008-09, Werth re-visited 50 of the same paddocks surveyed in 2001 by Charles et al. (2004) and Walker et al. (2005). Weed species and density were recorded early (November – December) and late in the cotton growing season (April – May) using the same method as in the survey by Walker et al (2005). An overview of the current practices used for weed control in dryland and irrigated cotton in the three regions were collected from CSD extension specialists in July 2010.

Data on the species and density of weeds surviving glyphosate applications to glyphosate-tolerant cotton in each region for 2003 to 2009 were suppled by Monsanto from the weed management audit process. This also included the remedial action taken in each paddock to control the survivors in 2007. The audit data came from an average of 611 paddocks in the Darling Downs, 442 in the Gwydir and 521 in the Lower Namoi regions.

Information on the extent and location of glyphosate resistant weeds in the three cotton regions came from the Australian Glyphosate Sustainability Working Group website (www.glyphosateresistance.org.au).

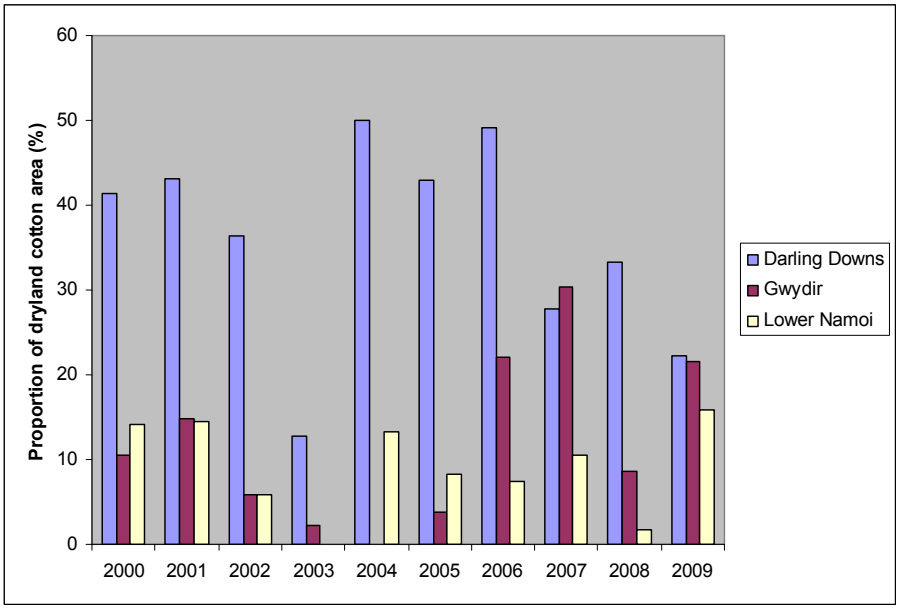

Figure 1. Changes in the proportion of dryland cotton production area since the introduction of herbicide tolerant cotton in three regions (source Cotton Yearbooks 2000-2009).

Findings and implications

The average cotton production area from 2000 to 2009 was the same in the Lower Namoi as on the Darling Downs (41500ha) and was greater in the Gwydir region (57400ha). The average proportion of dryland production was low in the Lower Namoi (9%) and the Gwydir (12%) but substantial on the Downs (36%), although these percentages varied between years (Figure 1). There was a trend towards more dryland in the Gwydir region and less on the Downs in the latter years, but reasonably consistent in the Lower Namoi region.

In dryland cotton systems, the one major change in the weed flora over the last decade was the increasing importance of flaxleaf fleabane (*Conyza bonariensis*), which moved from the 14th to the 2nd most common weed (Table 1). Bladder ketmia (*Hibiscus trionum*) continued to be the most common weed, and sowthistle (*Sonchus oleraceus*) was consistently prevalent. Changes in the weed spectrum were more evident in the irrigated cotton system, although bladder ketmia was consistently very prevalent. Both flaxleaf fleabane and sowthistle increased in prevalence considerably, and to a lesser extent Australian bindweed (*Convolvulus erubescens*), annual verbine (*Cullen cinereum*), caltrop (*Tribulus terrrestris*) and climbing buckwheat (*Fallopia convolvulus*). In contrast, cow vine (*Ipomea lonchophylla*), nutgrass (*Cyperus* spp) and barnyard grass (*Echinochloa colona*) tended to decrease in prevalence with time.

This indicates that there has been a major species shift to populations dominated by flaxleaf fleabane in dryland and irrigated systems, plus sowthistle as well as several other glyphosate tolerant weeds in irrigated systems.

Table 1. Ranking of the common weeds present in surveys of the same paddocks in 2001 and 2009 in dryland (Walker et al. 2005) and irrigated cotton systems (Charles et al. 2004).

Dryland paddocks	2001	2009	Irrigated paddocks	2001	2009
Bladder ketmia	1	1	Bladder ketmia	2	1
Flaxleaf fleabane	14	2	Flaxleaf fleabane	>20	2
Sowthistle	2	3	Sowthistle	13	3
Caltrop	4	4	Australian bindweed	11	4
Barnyard grass	6	5	Cow vine	1	5
Cow vine	7	6	Annual verbine	>20	6
Red pigweed	3	7	Caltrop	>20	7
Dwarf amaranth	5	8	Nutgrass	3	8
Australian bindweed	8	9	Barnyard grass	4	9
Liverseed grass	10	10	Climbing buckwheat	>20	10

The 2009 survey showed that the number of paddocks infested with the most common weeds were very similar between the dryland and irrigated systems (Table 2). However, there were less residual weeds in irrigated (mean of 13%) than in dryland paddocks (mean of 25%). The weeds controlled better in irrigated paddocks were sowthistle and bladder ketmia. The more important residual weeds were sowthistle, flaxleaf fleabane, bladder ketmia, barnyard grass and Australian bindweed in dryland systems, and cow vine, flaxleaf fleabane and Australian bindweed in irrigated systems. The number of dryland paddocks infested was similar for bladder ketmia and sowthistle, increased markedly for flaxleaf fleabane, but reduced for the other weeds between the 2001 and 2009 surveys.

Table 2. Percentage of surveyed paddocks with the most common 10 weeds early (November – December 2008) and late (March – April 2009) in the cotton growing season

Dryland paddocks	Early season	Late season	Irrigated paddocks	Early season	Late season
Bladder ketmia	77	36	Bladder ketmia	65	9
Flaxleaf fleabane	59	48	Flaxleaf fleabane	47	24
Sowthistle	59	64	Sowthistle	48	0
Caltrop	27	12	Australian bindweed	43	29
Barnyard grass	23	28	Cow vine	39	43
Cow vine	23	20	Annual verbine	30	10
Red pigweed	23	0	Caltrop	26	0
Dwarf amaranth	18	12	Nutgrass	17	0
Australian bindweed	18	24	Barnyard grass	17	14
Liverseed grass	18	4	Climbing buckwheat	17	0

Table 3. Percentage of paddocks with residual weeds as determined by the audits of glyphosate tolerant cotton from 2003 to 2009 in 3 regions and glufosinate tolerant cotton from 2007 to 2009 across the cotton growing region

Year	No. of paddocks	Amaranths	Barnyard grass	Burrs	Bladder ketmia	Flaxleaf fleabane	Nutgrass	Cow vine	Pigweeds	Sowthistle	Other grasses
Darling Downs (glyphosate tolerant cotton)											
2003	376	4	16	13	18	7	12	30	3	0	1
2004	420	2	16	7	26	12	8	24	6	0	0
2005	857	3	11	4	16	15	5	21	8	0	1
2006	406	2	5	3	15	4	7	20	10	3	1
2007	418	4	9	2	13	17	3	18	10	3	2
2008	791	0	8	2	18	21	3	33	12	-	0
2009	1009	0	5	0	12	13	4	34	3	-	1
Mean	**611**	**2.1**	**10.0**	**4.4**	**16.9**	**12.7**	**6.0**	**25.7**	**7.4**	**1.2**	**0.9**
Gwydir (glyphosate tolerant cotton)											
2003	141	0	15	4	6	10	25	21	1	1	0
2004	350	0	3	1	1	3	11	11	0	0	0
2005	873	1	5	1	5	28	7	26	1	1	0
2006	551	3	7	3	7	34	5	27	5	0	0
2007	233	0	5	0	0	31	18	18	8	1	0
2008	443	1	11	2	5	18	7	30	5		0
2009	500	0	7	0	5	24	6	24	6		1
Mean	**442**	**0.7**	**7.6**	**1.6**	**4.1**	**21.1**	**11.3**	**22.4**	**3.7**	**0.6**	**0.1**
Lower Namoi (glyphosate tolerant cotton)											
2003	340	0	9	5	9	2	29	19	1	0	0
2004	489	0	1	1	0	1	15	10	0	0	0
2005	825	1	2	0	2	6	9	11	2	1	0
2006	528	0	5	0	4	6	12	7	5	1	3
2007	333	0	4	1	2	4	19	11	5	1	0
2008	523	0	12	1	3	12	13	15	4		0
2009	609	0	6	0	1	11	9	11	5		1
Mean	**521**	**0.1**	**5.6**	**1.1**	**3.0**	**6.0**	**15.1**	**12.0**	**3.1**	**0.6**	**0.6**
Cotton growing area (glufosinate tolerant cotton)											
2007	4	0	0	1	0	0	0	0	0	0	0
2008	4	0	0	2	0	0	0	0	2	0	0
2009	11	1	3	0	0	2	0	0	0	0	0
Mean		**0.3**	**1.0**	**1.0**	**0.0**	**0.7**	**0.0**	**0.0**	**0.7**	**0.0**	**0.0**

The Monsanto audit data from over 1500 paddocks with glyphosate tolerant cotton showed that the main weeds surviving the glyphosate applications were cow vine, flaxleaf fleabane, nut grass, bladder ketmia, barnyard grass, pigweeds (*Portulaca oleraceus*), burrs (*Xanthium* spp), amaranths (*Amaranthus* spp), sowthistle and other summer grasses, but this differed between the regions (Table 3). The main surviving weeds were nutgrass and cow vine in the Lower Namoi; flaxleaf fleabane, cow vine and nutgrass in the Gwydir; and cow vine, bladder ketmia, barnyard grass and flaxleaf fleabane on the Downs. The trend over the 7 years of data showed that the percentage of paddocks with nutgrass and burrs was decreasing, which was contrasted with a general increase for pigweed and flaxleaf fleabane particularly in the Gwydir. It needs to be noted that cow vine and flaxleaf fleabane are not listed as weeds controlled by glyphosate on the Roundup Ready® Herbicide label.

The Bayer CropScience audit data were only from a limited number of paddocks in the last three years (lower section in Table 3). Currently, the numbers of surviving weeds are low, and it is too early to predict any potential changes in weed flora and infestation levels.

As well as a shift in the weed spectrum and changes in levels of infestation, 18 populations of barnyard grass and three populations of liverseed grass have developed glyphosate resistance in the three regions. Most of these populations evolved in grain farming systems but one was in a dryland cotton system.

Prior to the introduction of glyphosate tolerant cotton, weed control in cotton relied on use of residual herbicides applied pre-plant and/or at planting followed by in-crop post-emergent knockdown and residual herbicides applied as a layby or with a shielded sprayer (Table 4). These tactics were complemented with spot-spraying, inter-row cultivation and manual chipping of weed survivors and escapes, although to a lesser extent in dryland compared with irrigated cotton. An extensive number of herbicides were applied from 11 different modes of action groups.

Several years after the introduction of glyphosate tolerant cotton, weed management practices had started to differ between paddocks with conventional or glyphosate tolerant cotton (Table 4). Paddocks with transgenic cotton had less residual herbicides applied and marginally less selective post-emergent herbicides, inter-row cultivation and chipping used, but had greater amount of non-selective herbicides applied by directed, spot or shielded sprayers.

In contrast, the current trend is a dramatic reduction in the use of pre-emergent residual herbicides, non-selective herbicides applied by shielded, directed or spot sprayers, inter-row cultivation and chipping (Table 5). Overall, there were few main differences between the regions, apart from greater use of inter-row cultivation in irrigated cotton in the Gwydir region. The main consistent difference in tactics used in dryland and irrigated cotton was less inter-row cultivation in dryland crops. This could reflect the greater adoption of minimum till systems in dryland than in irrigated systems, less glyphosate tolerant cotton grown, as well as the differences in weed flora. Dryland cotton growers on the Darling Downs use pre-emergent residuals, inter-row cultivation and chipping to control flaxleaf fleabane.

As part of the stewardship (Crop Management Plan) associated with growing glyphosate tolerant cotton, growers are required to take remedial actions on survivors of the glyphosate applications. The main tactics used, as shown in the 2007 audit, were inter-row cultivation, herbicides applied by shielded sprayer or as a layby plus chipping, although the use patterns differed between the three regions (Figure 2). Cultivation was used more in the Gwydir and Lower Namoi regions, whereas herbicides applied by shielded sprayer and chipping were used more on the Darling Downs. Layby applications were used predominantly in the Gwydir region. These differences in remedial actions are likely to reflect the differences in area of dryland cotton grown (Figure 1) and differences in surviving weed species (Table 3).

Interestingly approximately 20% of Lower Namoi growers took no action, which may reflect that there were few survivors of many species in that region.

Overall, there has been a major change in the approach to weed management in paddocks sown with herbicide tolerant cotton. Growers have moved from almost universally applying residual herbicides in anticipation of a weed problem to dealing with the emerged populations using the knockdown, and previously non-selective, herbicide glyphosate plus one or several chemical and/or non-chemical tactics to control surviving weeds. These remedial actions focused particularly on the prevalent weeds or glyphosate tolerant weeds. A relatively new additional tactic is to rotate between glyphosate and glufosinate tolerant crops to control the glyphosate tolerant weeds with an alternative product. Thus, the majority of the industry appears to be returning to a more IWM approach to weed management within their cotton crops than in the remainder of the cropping system.

However, there has been a major shift in weed flora, which is now dominated by flaxleaf fleabane and sowthistle, while bladder ketmia, cow vine and nutgrass continue to flourish in the cotton cropping systems. Also, there appears to be more weeds surviving in the other components of the rotation compared with in cotton crops, as indicated by the difference between the Monsanto audit data and the 2009 field survey. This may reflect differences in extent of IWM used, levels of control achieved in different parts of rotation and widespread adoption of zero tilled systems particularly in the non-cotton components of the cropping system. Whilst the incidence of glyphosate resistant summer grasses is low, there a real risk of more populations evolving and being detected. Thus, with this threat of glyphosate resistant weeds and potentially more glyphosate tolerant weeds, there is a strong and urgent need to focus on IWM across the whole farming system and to target weeds at different parts of their life cycles to minimise replenishment of the seed-bank and to reduce existing seed-banks.

Table 4. Weed control tactics and herbicides used in survey dryland and irrigated cotton paddocks as recorded in 2001 surveys by Charles et al. (2004), Walker et al. (2005) and in irrigated conventional and glyphosate tolerant cotton in 2003 Werth et al. (2006)

Weed control tactics and herbicide MOA groups	**Irrigated cotton (2001)** Conventional and glyphosate tolerant cotton	**Dryland cotton (2001)** Conventional cotton	**Irrigated cotton (2003)** Conventional cotton	**Irrigated cotton (2003)** Glyphosate tolerant cotton
		% of paddocks surveyed		
Pre-plant residuals (grasses)	58			
Pre-plant residuals (broadleaf)	58			
At planting residuals (grasses)	42			
At planting residuals (broadleaf)	92			
Pre-emergence residuals		91	95	74
At planting knockdown (glyphosate)	17		44	44
Post-emergent (glyphosate)	25		0	100
Post-emergent (other)	8	5	21	13
Lay-by residual	67		67	62
Shielded spraying		93	18	64
Spot spraying			10	5
Inter-row cultivation	2.8 passes	80	92	87
Chipping	1.0 passes	80	80	72
	Active constituent		*% of paddocks surveyed*	
Group A		Fluazifop Haloxyfop	5%	3%
Group B	Pyrithiobac	Pyrithiobac	25%	15%
Group C	Diuron Fluometuron Prometryn	Diuron Fluometuron Prometryn	95%	80%
Group D	Pendimethalin Trifluralin	Pendimethalin Trifluralin	78%	60%
Group G		Oxyfluorfen	-	-
Group I		Fluroxypyr Triclopyr	13%	10%
Group K	Metolachlor	Metolachlor	8%	3%
Group L		Diquat + paraquat	8%	13%
Group M	Glyphosate	Glyphosate	68%	100%
Group Z	MSMA		-	-
		Regions		
	Macintyre Gwydir	Downs Macintyre	Downs Macintyre Gwydir Lower Namoi	Downs Macintyre Gwydir Lower Namoi
		No. farms / paddocks surveyed		
	19	48	40	40

Table 5. Weed management practices used in dryland and irrigated cotton crops in three regions (source: Cotton Seed Distributors)

Practice	Darling Downs		Gwydir		Lower Namoi	
	Dryland	Irrigated	Dryland	Irrigated	Dryland	Irrigated
	(% of area)					
Pre-emergence residual herbicide	20	10	<1	5	15	10
Pre-emergence knockdown herbicide	100	90	100	100	100	90
Roundup Ready over-application	85	90	90	95	85	99.9
Post-emergence herbicide (non-glyphosate)	2	2	<1	5	2	<1
Lay-by residual herbicide	30	25	15	20	50	15
Shielded spray	20	5	15	20	15	<1
Inter-row cultivation	20	30	<1	100	<1	25
Chipping	20	10	<1	10	10	2

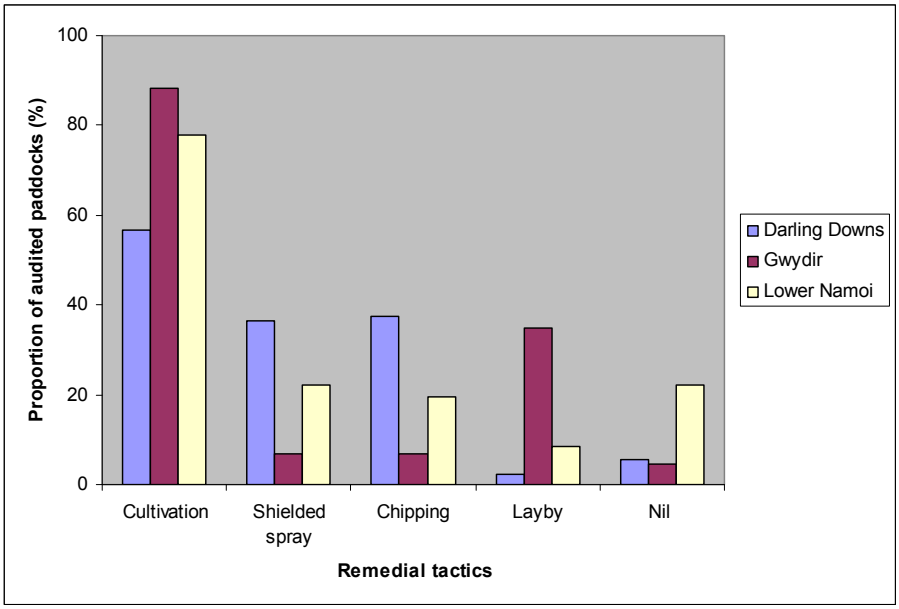

Figure 2. Tactics used as remedial action to control survivors of glyphosate applications in 3 cropping regions as recorded in the 2007 audit

Acknowledgements

We are grateful for assistance technical assistance from Luke Boucher, information from CSD extension specialists (Rob Everleigh, John Marshall, James Quinn) and Monsanto, and funding from CRDC and Cotton CRC.

References

Charles G, Taylor I, and Roberts G (2004) The impact of the cotton farming system on weed succession: implications for herbicide resistance and adoption of an integrated weed management approach. In *Proceedings of 14th Australian Weeds Conference*, pp 410-413.

Walker S, Taylor I, Milne G, Osten V, Hoque Z, and Farquarson R (2005) A survey of management and economic impacts of weeds in dryland cotton cropping systems of subtropical Australia. *Australian Journal of Experimental Agriculture* **45**, 79-91.

Werth J, Preston C, Roberts G and Taylor I (2006) Weed management practices in glyphosate-tolerant and conventional cotton fields in Australia. *Australian Journal of Experimental Agriculture* **46**, 1177-1183.