WEED MANAGEMENT STRATEGIES FOR HERBICIDE-TOLERANT COTTON

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SUMMARY

New weed species and resistance problems in 2012 are the ecosystem's response to our substantial changes in agronomy and weed management over the last two decades. Fleabane and feathertop Rhodes grass require targeted strategies for long-term control, and glyphosate resistance can be delayed or managed with a robust strategy. In all these cases, integrated use of pre-emergent and post-emergent herbicides, tillage and crop rotation is required, and results in a 'patchwork' approach to long-term sustainability of weed management. Simple systems, as we're observing right now, invite a confounding response from the weed flora, so more diverse and complex strategies will be needed in the future.

INTRODUCTION

Weeds are adaptable, which is why we study them (at least in part) under the banner of 'ecology'. Ecology suggests a community of organisms that has the propensity to change as environmental conditions change. Cotton paddocks, like all fields of annual agricultural crops, are frequently (even perpetually) disturbed ecosystems. Frequent disturbance favours–as we can easily observe–annual weeds that can lie dormant in the soil or move readily into empty spaces, and the pattern of disturbance (in our case, agronomy) favours particular weed species and biotypes. When the pattern of disturbance–the farming strategy–changes, species and biotypes that were previously not favoured can be selected and become common.

The change from one mixture of species to a different mixture takes time, however, and this lag in observable response to system change can fool us into believing that the shifts are not happening. Just as change is inevitable, however, responses to that change are too.

In the last five years or so, this change/response phenomenon has been played out in and around the cotton industry, in two very visible ways. Previously uncommon weeds have become common, or increased their range, and biotypes of common weeds that are resistant to key herbicides, and were once rare, have come to dominate local weed populations. These are responses to the widely-adopted change away from tillage and pre-emergent herbicides, and towards glyphosate.

CURRENT ISSUES IN WEED MANAGEMENT

Species shift We often consider newly-competitive species (such as current problem weeds flaxleaf fleabane and feathertop Rhodes grass) to be 'hard to kill'.

Table 1. Weed species prevalence ranking in cotton fields in two sequential field surveys in 2001 and 2010 (from Werth et al. 2010)

Rank	Weed Species	
	2001	**2010**
	Fields surveyed in dryland systems	
1	Bladder ketmia+	Flaxleaf fleabane*+
2	Sowthistle+	Sowthistle+
3	Pigweed	Bladder ketmia+
4	Caltrop/Yellowvine	Awnless barnyard grass
5	Dwarf amaranth*	Bindweeds*+
6	Barnyard grasses	Peachvine*+
7	Peachvine*+	Caustic weed
8	Australian bindweed*+	Paradoxa grass
	Fields surveyed in irrigated systems	
1	Peachvine*+	Flaxleaf fleabane*+
2	Bladder ketmia+	Sowthisle+
3	Nutgrass+	Peachvine*+
4	Awnless barnyard grass	Volunteer cotton*
5	Rhyncosia*+	Bindweeds*+
6	Annual verbine*+	Dwarf amaranth*
7	Volunteer cotton*	Bladder ketmia+
8	Physalis sp	Caustic weed

*Not on Roundup Ready® herbicide label
+Weeds that have a naturally high level of tolerance to glyphosate (Charles et al. 2004)

The reality is that they become prevalent due to changes in the weed management system. In the current case, neither species is very susceptible to glyphosate, and both do better in the absence of frequent soil disturbance. In other words, they are hard to kill using the methods of weed control that we have been progressively adopting over the last 10-20 years. In different systems, they have been (and may again be) lesser problems.

In recent work on changes to weed floras in dryland and irrigated cotton fields, Werth et al (2011) documented this by re-surveying fields assessed a decade ago (Table 1). Weeds typical of glyphosate-heavy, low-tillage farming (fleabane,

sowthistle) have become more common in the decade since 2001, and other previously-common species have become noticeably less prevalent (notably pigweed and caltrop). In the season since this work was completed, feathertop Rhodes grass has also become much more widely problematic, and would feature strongly on a new version of this list.

Because changes in weed flora are a response to industry's changing weed management and cropping practices, 'species shift' weeds can be dealt with by adding something to the current management regime – whether reviving old tactics that have fallen out of frequent use, or adding a new tactic.

Table 2. Percentage kill of flaxleaf fleabane plants using the "double-knock" tactic at Dalby in 2006. There were seven days between applications. (from Werth et al. 2010)

First knock	Second knock	% Weed kill
Roundup CT 2 L/ha	none	55
Roundup CT 2 L/ha	Spray.Seed 2.4 L/ha	97
Roundup CT 2 L/ha + Surpass 1.5 L/ha	Spray.Seed 2.4 L/ha	99
Roundup CT 2 L/ha + Surpass 3 L/ha	Spray.Seed 2.4 L/ha	100
Roundup CT 2 L/ha	Amicide 625 1.5 L/ha	94

Three tactics investigated over recent years for fleabane and feathertop Rhodes grass control are: the double knock (sequential application of glyphosate and/or a selective herbicide, followed a few days later by a bipyridyl, a tactic devised for hard-to-kill weeds in the post-tillage landscape) (Table 2); pre-emergent herbicides (an existing tactic but with particular herbicide requirements for fleabane) (Table 3); and tillage (an old tactic with new utility when used strategically) (Table 4).

Table 3. Seedling emergence of flaxleaf fleabane in plots treated with pre-emergent herbicides used in cotton. Millmerran, 2010.

Herbicide	Plants/10m^2	
	36 DAT	51 DAT
Nil	42	70
Pendamethalin 3.3 L/ha	35	75
Prometryn 2.5 kg/ha	0	2
Prometryn + Fluometuron 2.9 kg/ha	0	3
Norflurazon 1 kg/ha	5	2

DAT – days after treatment

These results are representative of a larger body of research work on tactics for these two weeds. In general, species-specific variations on the double knock are highly effective, and useful pre-emergent herbicides are available. The tillage results shown in Table 3 suggest that it is possible to favour these 'zero-till specialists' less, by including some strategic tillage.

Table 4. Emergence of flaxleaf fleabane and feathertop Rhodes grass (FTR) in plots treated with different tillage implements. Warwick, 2012

Tillage type	Emergence (% untreated)	
	Fleabane	FTR
Zero tillage	100.0	100.0
Harrows	9.0	30.6
Tynes	8.1	20.5
Offset discs	2.6	36.0
One-way disc	1.3	16.4

Glyphosate resistance We are used to thinking about glyphosate resistant weeds as an imminent or emerging threat. The period between 2010 and 2012, however, seems to have been the turning point: anecdotally, awnless barnyard grass populations in north-eastern Australia are now quite commonly glyphosate-resistant. That said, there are obviously very many major and minor weeds that remain (so far) susceptible to glyphosate, and many barnyard grass populations, too, that are still susceptible. So up-to-date weed management strategies must deal with delaying (or even preventing) resistance as much as possible, and with managing populations that do become resistant.

Table 5 Glyphosate resistance evolution and seed bank density of barnyard grass under strategies used in non-irrigated cotton crops (one crop per two years) with and without IWM in fallow

Additional tactics used in crop	Years to >99% resistant	Long-term seed bank density (seeds m^{-2})
Glyphosate-only summer fallows		
Glyphosate only	13	5354
PPPE	15	5065
PPPE+layby	17	2907
PPPE+2xIRT	21	780
PPPE+2xIRT every second crop	17	2891
IWM summer fallows		
Glyphosate only	17	3392
PPPE	19	3437
PPPE+layby	20	37
PPPE+2xIRT	>30	8
PPPE+2xIRT every second crop	17	18

PPPE – pre-planting pre-emergent herbicide
Layby – pre-emergent herbicide applied between rows mid-cropping
IRT – inter-row tillage
IWM summer fallows: early-season residual plus double knock, and glyphosate on subsequent cohorts

We used DAFF's model of glyphosate resistance evolution (Thornby & Walker, 2009) to test the effectiveness of a variety of resistance prevention

strategies. Our results for barnyard grass show that different frequencies and efficacies of non-glyphosate actions used in Roundup Ready Flex™ cropping can have very different long-term results. Robust systems are predicted to delay resistance substantially, but strategies without at least annual non-glyphosate actions were unsuccessful (Table 5). Overall, the two most striking outcomes from the modelling (including over 100 simulations not shown here) were: 1. Irrigated systems with annual cotton crops are consistently less likely to evolve resistance over the 30-year simulation timeframe than similar scenarios in dryland cropping (see Table 6); and 2. Actions taken in crop must be backed up by tactics used in summer fallows between dryland cotton crops. Where summer fallows are glyphosate-only, resistance evolves most rapidly.

Table 6.The effects of deliberately controlling barnyard grass glyphosate survivors at high or moderate efficacy at different frequencies in cotton

Treatments used to control glyphosate survivors	**Years to >99% resistant**		**Long-term seed bank density (seeds m^{-2})**	
	Irrig	D/L	Irrig	D/L
Nil	19	13	1497	5354
IRT multiple times per crop	>30	17	1	2565
IRT+man multiple per crop	>30	25	<1	4
IRT once per crop	22	13	815	3488
IRT+man once per crop	24	14	4	3439
IRT+man once per two crops	19	13	771	3439

IRT – Inter-row tillage at 80% efficacy
IRT+man – Inter-row tillage followed up with manual removal at 99.9% efficacy
Irrig – irrigated cotton, one crop per year
D/L – dryland cotton, one crop per two years

STRATEGIES

Principles for strategy development

The key principles for effective, long-term weed management are:

1. Know the weed spectrum and aim for maximum weed control
2. Stop seed set, actively manage the seed bank and control survivors to prevent replenishment
3. Monitor and respond to the success of your control tactics
4. Treat weed flushes with a diversity of in-crop and fallow management tactics
5. Don't automatically reach for glyphosate—think longer term

With these principles in mind, we can devise specific strategies to deal with the issues we're faced with today. A robust strategy for cotton would include the following cycle of activities:

1. Plan strategies in advance, before the start of the season, and including some diversity of tactics
2. Employ those tactics/strategies
3. Monitor their success in the field
4. Take effective remedial action to prevent seed bank replenishment when required

Managing fleabane in cotton systems

In order to deal with specific hard-to-kill weeds, several tactics can be combined into an effective strategy. Keeping in mind that all strategies should follow the basic principles of diversity of tactics, planning, monitoring, and responding as described above, the following are useful elements of a fleabane management strategy:

- Double knock (with glyphosate + broadleaf herbicide, followed by bipyridyl or full cultivation) prior to planting, for a clean start to the season
- Apply an effective pre-emergent herbicide or herbicide combination prior to or at planting
- In crop actions can include:
  - Early- or mid-season directed residual herbicide (layby)
  - Shielded bipyridyl following in-crop Roundup Ready Herbicide in Roundup Ready Flex™
  - Inter-row cultivation and chipping or spot-spraying

An intense control strategy implemented over three years should substantially reduce the seed bank, providing the weed is not allowed to persist in non-crop areas.

Dealing with glyphosate resistance

Results from our work on modelling resistance prevention and management can be distilled into the following principles:

- Two non-glyphosate tactics in-crop plus two in summer fallows provides long-term delays in resistance evolution
- Pre-emergent herbicides are an important tool, but should be backed up with non-glyphosate knockdowns and strategic tillage
- Getting very high efficacy is important for controlling glyphosate survivors, but controlling survivors more often (i.e. in multiple cohorts) is more important
- For best control of resistant weed populations, start a management strategy (including non-glyphosate options) before resistance comes to dominate the population
- If only a limited number of non-glyphosate tactics can be afforded, it is better to use them multiple times in one year than to spread them over several years
- Use a robust program of resistance prevention and management in non-crop areas as well as cropped paddocks

Non-crop areas, including irrigation channels and roadways, are at high risk of species shift and resistance just as cropped areas are, and prevention and management strategies are theoretically no different, though the tools used may differ. That said, if areas adjacent to cropped paddocks do have glyphosate-resistant barnyard grass (or indeed weeds of any specific kind) and your in-crop areas don't, then in a practical sense your in-crop management strategies can be said to be working well. There may be longer-term consequences, but any strategy that can deal consistently with nearby sources of resistant seeds is a useful one.

Using the weed control threshold in cotton

The resistance-delaying benefits of IWM can be further improved by minimising glyphosate use in-crop.. This can be achieved using the weed control threshold in cotton to identify the timing of glyphosate applications that will allow the fewest applications to be made, reducing resistance selection pressure while avoiding yield losses (Charles & Taylor 2009). Over-threshold weed populations need to be controlled ASAP, but below-threshold populations can be monitored to allow further emergence before control is required. Further information on the threshold technique can be found in section B4 of "WEEDpak – a guide for integrated management of weeds in cotton" on the web at: cottoncrc.org.au/Industry/Publications/Weeds.

It is essential, however, that weed populations are still managed to prevent seed set (Charles, 2009). Information on the growth and development of some of the more problematic weeds of cotton (section A3 of WEEDpak) can be used to estimate how long control can be delayed before viable seed is produced and how much seed might be produced by uncontrolled plants.

CONCLUSIONS

The weed science community's response to shifts in species frequency and the evolution of resistance has been, in typical scientific fashion, to ask questions: What is happening? Why? How quickly? What could be done to prevent it, or slow it down? How do we deal with the new conditions? Our answers to these questions are distilled into tools and strategies that allow growers to respond to the new environment. Effective strategies that are used appropriately are clearly a good way forward towards having the industry remain viable, profitable and sustainable in the face of change.

However, it is equally clear that whatever the new weed management regime is, the weed flora will change again in response to it. 'The Weed' as a generic problem is extremely resilient. Whether the response involves rare traits (like glyphosate resistance) or formerly-innocuous species (like fleabane and feathertop Rhodes grass), history suggests that new weeds will be preferentially selected and, if the system is not sufficiently diverse, come to confound it sooner or later.

Our current (and historical) method is to adjust our toolkits to chase new 'favoured-status' weeds after they become problematic—as we've done with fleabane by adding the double knock tactic. This approach can continue to work, provided the right tools remain available and growers are willing and able to change strategies in a timely fashion. The alternative, though, is to emphasise diversity, using many tactics in an intelligent way and supported by as many useful technologies as possible. A diverse system offers the best chance to control the greatest number of current weed species, as well as the greatest number of newly-problematic species or biotypes as (or before) they emerge as issues. Importantly, a robust, diverse system can be consistent over long periods of time, thus reducing the likelihood of large, hard-to-solve responses by the ecosystem along the lines of what we're dealing with today.

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