Managing weed resistance to herbicides

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Update on herbicide resistance

Herbicide resistance is an ever increasing hurdle for sustainable agriculture, not only in Australia but worldwide. Currently there are 319 resistant biotypes of 185 weed species that are resistant to herbicides from the majority of herbicide mode of action groups across the globe (Heap 2008). To glyphosate alone there are 13 resistant species world wide, two of which include populations of awnless barnyard grass and annual ryegrass in Australia. A closer examination of the situation in Australia shows that there are populations of 34 weed species resistant to 12 herbicide mode of action groups (Table 2 contains a list of these groups). Whilst the majority of these species are located in southern Australia, a significant number of these weeds are those that can be found in cotton growing regions, whether in the cotton crop itself or in other parts of the rotation (Table 1).

Table 1. Weed species found in cotton growing regions that have populations resistant to herbicides (Heap 2008).

Weed	**Herbicide**
Annual ryegrass	Wildcat, Fusilade, Verdict, Targa, Sertin, Glean, Ally, Logran, Trifluralin, glyphosate
Wild radish	Glean, Ally, Logran
Wild oat	Select, Topik, Hoegrass, Wildcat. Mataven L
Awnless barnyard grass	glyphosate, atrazine
Paradoxa grass	Wildcat, Sertin
Charlock	Glean
Indian hedge mustard	Glean
Climbing buckwheat	Glean
Turnipweed	Glean
African turnip weed	Glean
Sowthistle	Glean
Liverseed grass	atrazine

The introduction of glyphosate-tolerant cotton has potential to increase the risk of glyphosate resistance evolution. Whilst there are still no known cases of glyphosate resistance in cotton fields after 8 years, one case of awnless barnyard grass resistance has appeared in an area relatively close to cotton fields, and the number of suspected cases is growing.

If we look outside Australia to examples of glyphosate-tolerant crops in other countries, there are some valuable lessons to be learned. In the United States and South America glyphosate has largely replaced other herbicides and tillage in glyphosate-tolerant cropping systems. Seven weeds have been confirmed resistant since the introduction of glyphosate-tolerant soybean and cotton in the US in 1996. Weed shifts to species more tolerant of glyphosate such as fat hen and pigweed have also been observed in glyphosate tolerant corn. Four weed species have evolved glyphosate resistance since the introduction of glyphosate-tolerant soybeans in South America.

Canada stands as an example of how a diverse cropping system minimises the glyphosate selection pressure. In the western grainbelt provinces, canola is the only glyphosate tolerant crop in a rotation with wheat and barley. Glufosinate-tolerant canola is also grown and competes directly with glyphosate-tolerant canola. On average, canola is grown only one year in four mainly due to the need to manage the fungal disease blackleg. Nevertheless in this system there are currently no known glyphosate resistant weeds, and as a result the use of glyphosate- and glufosinate-tolerant canola should remain sustainable.

Latest research on glyphosate resistance in the northern region

The latest research into herbicide resistance in Australian cropping weeds continues to focus on the key areas of mechanisms of resistance and the influence of farming systems and practices on resistance evolution. This farming systems research covers both prevention of new resistance cases and management of existing resistant weed populations. Glyphosate resistance is the main focus of herbicide resistance work around Australia, given the importance of this herbicide to farming systems worldwide.

In the case of mechanisms, significant work is being done concerning the recent confirmation of glyphosate resistance in barnyard grass populations of northern Australia. Resistance testing facilities at the University of Adelaide have tested several awnless barnyard grass populations for glyphosate resistance – two populations from northern NSW have been confirmed as resistant and a third, from Goondiwindi, was found to be resistant and is awaiting re-testing for confirmation (Chris Preston, Peter Boutsalis, pers. comm.). Early molecular work suggests that the barnyard grass populations have a relatively weak target site resistance mechanism (Chris Preston, Fleur Dolman pers. comm.). Similar work has been carried out on glyphosate resistance mechanisms in annual ryegrass.

A significant amount of work has been done in recent years on the influence of farming systems and practices on the rate of evolution (and therefore prevention) of herbicide resistance, and management of existing resistant populations. In the northern region, surveys of resistance risk for key weed species were undertaken to identify those species that warranted further work and close monitoring (Walker et al. 2004). This provided significant grounding for ongoing research into preventative strategies for these important weeds. The double knock (sequential application of two knockdown herbicides from different mode of action groups) as a resistance prevention tactic has been tested over several seasons for species such as fleabane, barnyard grass, sweet summer grass, and annual ryegrass (Werth et al., included in these proceedings). Computer modelling has reinforced the theory that integrated weed management (IWM) strategies are able to prevent or significantly slow the development of high levels of glyphosate resistance in important summer grass weeds. Computer simulations have predicted that the use of a range of IWM strategies in irrigated herbicide-tolerant cotton crops could negate or significantly reduce the rate of evolution of glyphosate resistance in barnyard grass and liverseed grass (Figure 1). Modelling of barnyard grass in northern Australian grains farming predicted that paddock risk levels for glyphosate resistance are reduced where methods of controlling glyphosate survivors are used annually even after several years of complete reliance on glyphosate (Figure 2). This research also suggests that a program of controlling seed set on glyphosate survivors, such as the use of double knock is an effective way to manage resistant weed seed banks, particularly where seed banks are kept low at the time resistant plants start to dominate the population.

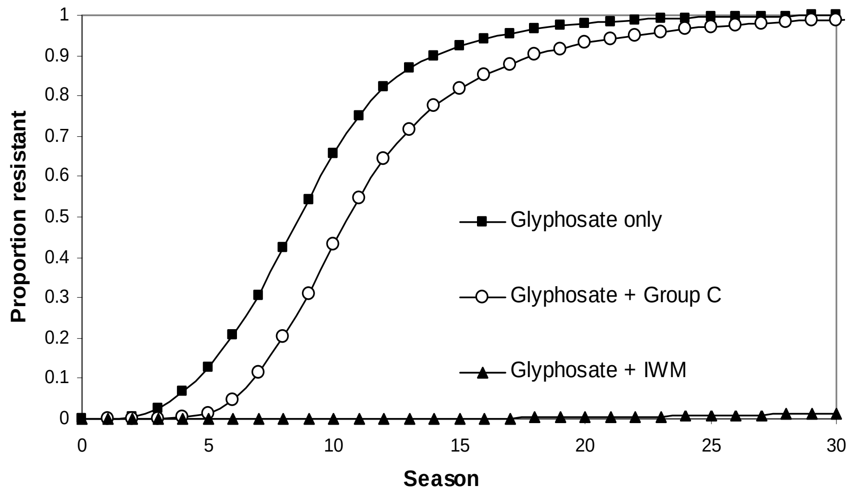

Figure 1. Predicted rate of barnyard grass resistance evolution in glyphosate-tolerant cotton with an initial resistance gene frequency of 1 in 1,000,000.

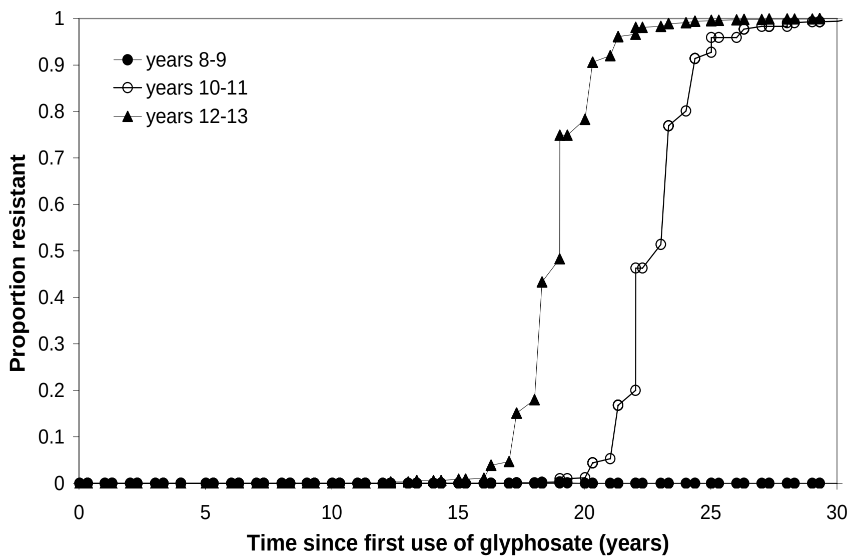

Figure 2. Predicted evolution of glyphosate resistance in barnyard grass under zero-till summer fallows with reliance on glyphosate plus three double knock regimes: two years of double knock on every weed flush in the years specified, followed by double knock annually on the largest flush

Information from modelling and field research conducted in the northern region in the last three years has been used to establish risk ratings for typical northern grain farming systems and practices. Risk tables like the one in Table 2 and more detailed risk questionnaires allow growers to assess the risk level of their current and historical practices, without needing to read a full set of predictions and graphs for a wide range of farming systems and practices.

Table 2. A sample two-factor risk assessment matrix for glyphosate resistance in barnyard grass

		No-till fallows with glyphosate use for how many years?			
		5	7	10	15
# summer crops per 5 years since start of no-till	0	Med	Med	*High*	*High*
	1	Low	Med	*High*	*High*
	2	Low	Med	*High*	*High*
	3	Low	Low	Med	Med
	4	V Low	Low	Low	Low
	5	V Low	V Low	V Low	Low

Given that glyphosate resistant barnyard grass has emerged in the last two years as a likely significant issue for northern region farming, research has been underway into managing resistant populations of this weed. The NSW Department of Primary Industries have investigated alternatives to glyphosate and the efficacy of double knock tactics on glyphosate resistant barnyard grass, and results indicate that a full range of selective and broad spectrum options are effective (Storrie et al. 2008). Double knock with glyphosate followed by paraquat was found to be highly effective, particularly where the plants were sprayed while small. It is important to note that these findings are as important for resistance prevention as they are for management of resistant populations: a wide range of options should always be considered as part of a strategy of herbicide rotation.

Research into herbicide resistance mechanisms, prevention, and management continues. Key research areas in the near future include:

- extension of the northern region glyphosate resistance model to include herbicide tolerant and conventional cotton
- formation of a web-based risk assessment tool for growers to assess their resistance risk on a field by field basis
- continuing research into the mechanisms of glyphosate resistance in barnyard grass
- experimentation to better understand the ecology of key resistant weeds and particularly the behaviour of their soil seed banks
- understanding the best and most sustainable ways to introduce herbicide tolerant cotton varieties into northern dryland grains farming systems

The recent formation of a new National Integrated Weed Management Initiative (NIWMI) will provide nation-wide collaboration and integration of research projects in the area of herbicide resistance, which is critical for sustaining the profitability of a range of cropping systems in Australia – particularly for continuing our ability to make best use of herbicide tolerant crop technologies.

Key messages for management

The two most important features for a resistance prevention and/or management plan are: field monitoring and field records, with the success of weed management strategies hinging on these. The evolution of herbicide resistance can be basically put down to two factors: a) the initial frequency of/or likelihood to find a resistance gene in a given weed population; b) the selection pressure or the herbicide use pattern applied to that population. Looking at these factors in turn, we will see how they apply to weed management involving field monitoring and records.

Essentially, the potential for resistance relates to numbers. As the number of plants in a population increases, so does the potential of a resistant individual being present, simply due to genetic variation (such as a characteristic for a rare disease in people). For example, the initial frequency of annual ryegrass plants resistant to group B herbicides in previously untreated populations was found to range from 1 in 8,000 to 1 in 100,000 (Preston and Powles 2002). The frequency of a glyphosate resistant plant being present in a population is estimated at somewhere around 1 in 100,000,000. Hence the chance of resistance occurring is much lower for glyphosate than a group B herbicide. In a 100 ha paddock, if the likely frequency of a resistant individual is 1 in 1,000,000, it only requires one plant per square metre for a resistant individual to potentially occur. Therefore fields with high densities of plants are more likely to contain resistant individuals.

Selection pressure is the other important factor in resistance evolution. It is related to the management or herbicide use pattern applied to a weed population. In terms of glyphosate resistance, a situation of high selection pressure for glyphosate resistance is one which permits a glyphosate resistant individual in a population a much higher chance of surviving, setting seed and reproducing than a susceptible individual. Consider a field that contains a population of weeds where one plant is resistant to glyphosate. If that field is continuously sprayed with glyphosate and no other herbicides or tillage are used, that resistant plant has a much greater chance of reproducing than other plants in the population, and the progeny will most likely also have this advantage over the progeny of a susceptible plant. If this continues for many generations, eventually the whole field will be dominated by glyphosate resistants plants originating from the initial one. If another herbicide or tillage are used, the chance of survival of the glyphosate resistant plant is much lower – and usually is similar to the chance of survival for a glyphosate susceptible plant.

Therefore, preventing and/or managing resistance involves managing these two factors. The initial frequency of a resistance gene is reliant upon nature, but keeping weed numbers as low as possible minimises the chance of a resistant individual being present. The selection pressure placed on weed populations is determined by the management strategy imposed. In situations where herbicide-tolerant crops are grown, this becomes increasingly important. In the case of glyphosate, there is opportunity to use glyphosate in-crop as well as in fallow, thus increasing the selection pressure placed on weed populations throughout the whole rotation.

The crop management plans for both glyphosate- and glufosinate-tolerant cotton revolve around minimising the selection pressure which favours resistance to those herbicides used on a weed population. This is why there is a requirement to prevent seed set on survivors of glyphosate or glufosinate applications. Controlling a survivor can stop it reproducing and multiplying, thus reducing the selection pressure for resistance to a particular herbicide. This is where the role of field monitoring becomes important. If a field isn't monitored for survivors of a herbicide application, whether it be glyphosate in glyphosate-tolerant cotton or in fallow, any survivors will reproduce. If these survivors are found and controlled before they set seed and this is confirmed by effective monitoring, there will be no issue. Problems are only likely to occur when herbicide survivors are allowed to set seed.

Rotating herbicide mode of action groups and using tillage are critical components for minimising selection pressure and preventing or managing resistance. Rotating crops also provides an opportunity to use herbicides from different mode of action groups. It is therefore important that we are familiar with these herbicide groups and their relative resistance risk evolvement over years of application. These are listed in Table 3; however a more detailed list of herbicide mode of action groups can be obtained from CropLife Australia (www.croplifeaustralia.org.au). Note that the risk of resistance to glyphosate is considered medium, but if this is the sole herbicide used in both crop and fallow the risk increases. This highlights the importance of keeping field records: if herbicides from one or a few mode of action groups have been used in a field, it is probably time to look for a herbicide from a different group.

Table 3. Years of herbicide application before resistance evolves (adapted from Preston et al. 1999)

Herbicide group	Years of application	Herbicide resistance risk
A (Fops, Dims, Dens)	6-8	High
B (SU's; glean, ally. IMI's; flame, spinnaker)	4	High
C (atrazine, prometryn, fluometuron)	10-15	Medium
D (trifluralin, pendamethalin)	10-15	Medium
F (norflurazon)	10	Medium
I (phenoxies)	Not known	Medium*
L (paraquat/diquat)	15+	Medium*
M (glyphosate)	15+	Medium*
N (glufosinate)	Not known	Medium*

*These herbicide groups were previously considered to be at a low risk of evolving resistance.

The CRC for Australian Weed Management has produced a training resource for farm managers on integrated weed management which covers these areas in more details (McGillion and Storrie 2006). This is available at http://www.weedscrc.org.au/publications/education_training_resources.html.

Putting it all together

When preparing a weed management plan it is important to consider the following points:

- What are the key weed species in each field, and how dense are they? Different species may require specific management. If the field is dense with weeds it is important that weed control does not rely on one herbicide (i.e. glyphosate in glyphosate-tolerant cotton). If a field has a low weed pressure, careful monitoring also needs to be practiced.
- What is the history of herbicide use in the field? Although glyphosate-tolerant cotton may have only been used in a field for a couple of years, it is important to know what herbicides have been used in other crops and fallows prior. Glyphosate may have been heavily relied upon in fallows long before the introduction of glyphosate-tolerant cotton.
- What herbicides are effective on the key weeds in each field, and when is the best time to use them? In the case of awnless barnyard grass, it is controlled well by glyphosate, paraquat, group A herbicides such as Verdict® and some residual herbicides. In a rotation containing glyphosate-tolerant cotton, glyphosate will be used in-crop. However to minimise the glyphosate selection pressure, residual or post-emergent herbicides can also be used. It should also be noted that glyphosate should not be solely relied upon in fallow: this is an opportune time to use paraquat (group L) or perhaps even a residual (keeping in mind they have a medium resistance risk). Table 2 shows that Verdict (group A) has a high risk of developing resistance, so its use should be limited to in-crop applications rather than in fallow.
- Last but not least, when can tillage be used? There are a number of opportunities, particularly in irrigated cotton, where tillage can be used. These include pupae busting, incorporation of fertilisers, seed bed preparation and maintaining irrigation furrows. It is possible that these operations can be timed to combine with weed control measures. No herbicide resistance can evolve to 'cold hard steel'.

Revisiting the Canadian experience with herbicide-tolerant canola, we can see the benefit of rotations between glyphosate- and glufosinate-tolerant varieties and other crops to reduce the selection pressures imposed on weeds and minimise the risk of resistance. We now have the ability to adopt a similar approach with our cotton varieties. It is essential that the whole rotation is considered, records are made of herbicides used and their effectiveness, and fields are monitored for survivors so the benefits of a resistance prevention or management plan can be maximised.

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