Managing glyphosate resistant weeds in Australia

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Summary Glyphosate resistance has evolved in three grass weed species in Australia. By far the greatest problem is with *Lolium rigidum* Gaudin, but more recently resistant populations of *Echinochloa colona* (L.) Link and *Urochloa panicoides* P.Beauv. have been reported. Glyphosate resistance occurs in a wide range of situations including grain cropping, chemical fallows, in orchards, vineyards, along irrigation channels, along fence lines, railway rights of way and roadsides. Glyphosate resistance occurs where glyphosate has been intensively used, either once or many times per year, where no other effective herbicides are applied and where no other effective weed management is conducted. The rate and annual intensity of glyphosate use is not well correlated with the appearance of glyphosate resistance. Instead, the lack of other weed management practices is a better predictor of resistance. The Australian Glyphosate Sustainability Working Group (AGSWG) is a cross-industry group with the aim of identifying and disseminating key information and strategies for the management of glyphosate resistant weeds to all sectors in Australia. It provides information on confirmed cases of resistance, answers to glyphosate resistance issues and strategies for management of glyphosate resistance. By providing clear and consistent messages about glyphosate resistance across industry sectors it is hoped to reduce the incidence and impact of glyphosate-resistant weeds.

Keywords Glyphosate resistance, *Lolium rigidum*, *Echinochloa colona*, *Urochloa panicoides*, Australian Glyphosate Sustainability Working Group.

INTRODUCTION

Glyphosate is widely used in agricultural and non-agricultural systems in Australia. Glyphosate has several key attributes that make it a valuable herbicide. Glyphosate is a broad spectrum herbicide that effectively controls many annual and perennial weeds. It has no soil activity, allowing the sowing of crops shortly after application. Glyphosate has low mammalian toxicity making it an ideal herbicide for use by non-professionals (Bayliss 2000, Duke and Powles 2008). These factors and the relative cheapness of glyphosate make this the most widely used herbicide in the world (Duke and Powles 2008).

In Australian grain production, glyphosate is used to control weeds prior to seeding of annual crops. It is also used to control weeds in summer and winter fallows. In addition, glyphosate can be used to control weeds between rows of certain crops and over the top of glyphosate-tolerant cotton and canola. Glyphosate is also used to control weeds along fence lines and crop margins, around sheds, along irrigation channels and in other un-cropped areas of the farm. In horticulture, glyphosate is used to control weeds under trees and vines and for weed control prior to planting horticultural crops. Glyphosate is used to control woody weeds in forestry and native ecosystems. Glyphosate is widely used by local government for the control of weeds along roadsides, on footpaths, around structures and in parks and gardens. It is also the most important herbicide sold for home garden use.

These many uses of glyphosate make it the most versatile herbicide used in Australia (Powles 2008). The loss of glyphosate could seriously impact the efficiency and profitability of agricultural enterprises. Therefore, the evolution of glyphosate resistance in *Lolium rigidum* Gaudin in Australia in 1996 (Powles *et al.* 1998, Pratley *et al.* 1999) created significant concern. Since then glyphosate resistance has evolved in two other grass weed species in Australia and in several weed species elsewhere in the World (Powles 2008). This paper will briefly review the current situation with glyphosate resistance in Australia and discuss approaches to the management of glyphosate-resistant weeds.

GLYPHOSATE-RESISTANT WEEDS IN AUSTRALIA

Glyphosate resistance was first reported in populations of *L. rigidum* from a no-till farming operation near Echuca, Victoria (Pratley *et al.* 1999) and shortly afterwards from an apple orchard near Young in NSW in 1996 (Powles *et al.* 1998). Over the intervening 13 years the number of populations of *L. rigidum* resistant to glyphosate reported in Australia has continued to increase (Figure 1). At present there are 103 confirmed populations of *L. rigidum* with resistance to glyphosate (Preston 2009).

In 2007 glyphosate resistance was reported in a population of *Echinochloa colona* (L.) Link from a summer fallow, winter cereal production situation near Moree, NSW (Storrie *et al.* 2008). In 2008 glyphosate resistance was reported in a population of

Urochloa panicoides P. Beauv. from a summer fallow, winter cereal production situation near Moree, NSW. At present there are five confirmed glyphosate-resistant populations of *E. colona* and two confirmed glyphosate-resistant populations of *U. panicoides* in Australia (Figure 1).

While the first two populations of *L. rigidum* to evolve glyphosate resistance in Australia did so in a no-till cropping field and an orchard, these have not been the situations where most resistance has evolved (Table 1). The most confirmed sites with glyphosate-resistant *L. rigidum* are in intensive winter fallow, summer crop production systems in northern NSW. The second largest number of confirmed sites of glyphosate-resistant *L. rigidum* is fence lines and crop margins. Glyphosate-resistant *L. rigidum* is not limited to agricultural enterprises having evolved along railways and roadsides treated with glyphosate as well. Currently all of the confirmed populations of *E. colona* and *U. panicoides* occur in summer fallow, winter grain production systems (Preston 2009).

An examination of the situations where glyphosate-resistant weeds have evolved in Australia indicates the land uses most at risk are where glyphosate is used intensively, often several times per year, and no other effective weed management practices are employed (Preston *et al.* 2009). However, the rate and annual intensity of glyphosate use is not well correlated with the evolution of glyphosate-resistant weeds. Glyphosate resistance has evolved in situations where the herbicide is applied at rates over 1 kg ha^{-1} several times per year in vineyards and orchards over 15 years (Powles *et al.* 1998, Wakelin *et al.* 2004, Wakelin and Preston 2006). Glyphosate resistance has evolved over the same time period in no-till grain production where the selection intensity is lower (Neve *et al.* 2004, Pratley *et al.* 1999). Likewise, resistance has evolved on fence lines and crop margins where glyphosate is typically only applied once per year (Preston *et al.* 2009).

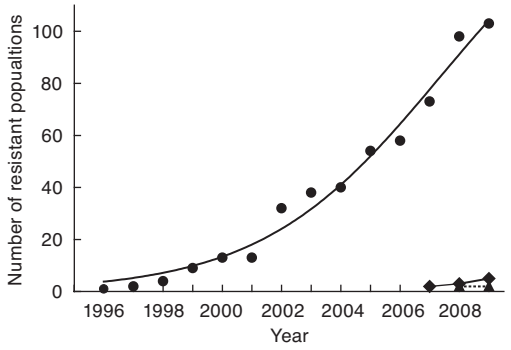

Figure 1. The increase in confirmed cases of glyphosate resistance in *L. rigidum* (●), *E colona* (♦) and *U. panicoides* (▲) in Australia from 1996 to 2009. From Preston (2009).

Table 1. Agricultural and non-agricultural land uses reporting glyphosate-resistant *L. rigidum* in Australia. From Preston (2009).

Situation		Number of sites	States
Grain production	Chemical fallow	28	NSW
	Winter grain production	19	Vic, SA, WA
Horticulture	Tree crops	4	NSW
	Vine crops	15	SA, WA
Other	Driveway	1	NSW
	Fence line and crop margin	25	NSW, SA, Vic, WA
	Irrigation channel	8	NSW
	Airstrip	1	SA
	Railway right-of-way	1	WA
	Roadside	1	SA

MANAGEMENT OF GLYPHOSATE-RESISTANT WEEDS

The continued employment of glyphosate-only weed control will inevitably lead to additional weed species evolving glyphosate resistance and the current weed problems spreading (Powles 2008). The loss of efficacy of glyphosate for the control of weeds presents a significant challenge to effective weed control. As a result there has been considerable interest in developing strategies to manage glyphosate-resistant weeds.

Various strategies have been proposed for the management of glyphosate-resistant weeds in Australia. These include using alternative herbicides, employing paraquat + diquat following glyphosate application, a strategy called the 'double knock' (Borger and Hashem 2007, Neve *et al.* 2003), and the use of crop competition and weed seed set control (Wakelin and Preston 2008). It is clear that a single strategy will not be effective for all situations.

The strategies employed to manage glyphosate-resistant weeds will depend on the situation where the weeds occur. In some situations, such as chemical fallows, there are a limited number of control options available, greatly constraining management

choices (Storrie *et al*. 2008). In other situations, such as irrigation channels, using a herbicide other than glyphosate may not be an available option. To date, the most successful strategies to manage glyphosate-resistant *L. rigidum* have included several different control strategies and employed tactics to reduce seed production of glyphosate-resistant individuals (Preston *et al.* 2009). In these strategies, glyphosate may still be used, but is relied on less. Simply continuing to rely mostly or entirely on glyphosate has been ineffective (Wakelin and Preston 2008).

THE ROLE OF THE AUSTRALIAN GLYPHOSATE SUSTAINABILITY WORKING GROUP

As glyphosate is such a widely used and important herbicide in Australian agriculture, it has been important to take a whole of industry approach to the management of glyphosate resistance. Widespread and extensive resistance to glyphosate will increase the cost and difficulty of managing weeds in agricultural systems. This highlights the need to have effective management strategies for management of glyphosate-resistant weeds.

The Australian Glyphosate Sustainability Working Group (AGSWG) was first established in 2004 by the Grains Research and Development Corporation (GRDC) and the Cooperative Research Centre for Australian Weed Management to develop strategies to combat the increase in glyphosate-resistant weeds. The participants in the AGSWG include public sector researchers, agricultural industry representatives and representatives from the herbicide industry (AGSWG 2009). The role of the AGSWG is to identify key extension messages for delivery to glyphosate users in agricultural and non-agricultural sectors in order to reduce the risk of glyphosate resistance evolving. AGSWG prepares and disseminates information about the evolution and management of glyphosate-resistant weeds. This includes answers to frequently asked questions and industry specific management strategies. The material is freely available from the AGSWG website (AGSWG 2009).

An important activity of the AGSWG is to develop and deliver clear and consistent messages about the risks of glyphosate-resistant weeds and their management. Users are more likely to take action to manage glyphosate resistance if they receive a consistent message, rather than mixed messages from different sectors. The AGSWG collaborates across industry sectors to achieve this goal. The ASGWG is a novel collaboration in weed resistance management in that it includes industry, commercial and academic input to better manage this important problem.

CONCLUSIONS

Glyphosate-resistant weeds have evolved in both agricultural and non-agricultural sectors across Australia from the intensive use of glyphosate for weed control. The risk factors for the evolution of glyphosate-resistant weeds have been identified as continual use of glyphosate for weed control with no other effective weed management strategies employed. Continued use of glyphosate in this fashion will inevitably result in additional populations and weed species with glyphosate resistance in Australia.

The most effective management strategies for glyphosate-resistant weeds involve the use of alternative effective weed management strategies, competition where appropriate and weed seed set control where appropriate. The AGSWG has played a key role in identifying and distributing information about glyphosate-resistant weeds in Australia. In particular it has provided clear messages about the risks of glyphosate resistance and management options to users. The collaboration of researchers, industry and commercial sectors has enabled this to occur.

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