Impact of management on glyphosate-resistant *Lolium rigidum* populations on farm

Angela M. Wakelin[1] and Christopher Preston[1,2]
[1] School of Agriculture, Food and Wine, University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia
[2] CRC for Australian Weed Management
Email: christopher.preston@adelaide.ed.au

Summary Glyphosate resistance in *Lolium rigidum* Gaudin has appeared in 64 known locations across Australia since 1996. A variety of management strategies have been suggested for managing glyphosate-resistant *L. rigidum*; however, there is no surety that these strategies will reduce the impact of glyphosate-resistant weeds in all situations. A survey was conducted to determine the impact of management on glyphosate-resistant *L. rigidum* populations in the field. Populations were successively sampled from fields with glyphosate-resistant *L. rigidum* and tested for resistance to glyphosate. The percentage of the population resistant to glyphosate decreased at two sites where glyphosate was not used alone for weed control. At the third site, where glyphosate was the only effective herbicide, the percentage of resistant individuals increased. With intensive management it is possible to reduce glyphosate resistance to low levels.

Keywords Glyphosate resistance, management, *Lolium rigidum*.

INTRODUCTION

Glyphosate is an important herbicide in Australian cropping systems and horticulture (Powles *et al.* 1998). In grain cropping, it is primarily used for the control of weeds prior to crop seeding. Glyphosate can also be used in some crops for inter-row weed control or applied late in the season to control seed set of weeds. In horticulture, glyphosate is used for the control of weeds underneath trees or vines. In addition to uses on crops, glyphosate is also used for weed control in non-cropped areas of the farm, including around sheds, along irrigation channels and fence lines.

The intensive use of glyphosate for weed control resulted in the evolution of glyphosate resistance in *L. rigidum* in 1996 (Powles *et al.* 1998). Subsequently, glyphosate resistance has appeared in 64 populations of *L. rigidum* and more recently in populations of *Echinochloa colona* (L.) Link (Preston 2007). Management of glyphosate-resistant weeds is vital, as there are few useful alternatives available in some situations. In order to understand the impact of glyphosate resistance management strategies on glyphosate-resistant weed populations, we surveyed several sites of glyphosate-resistant weeds to determine the effect of management on the frequency of glyphosate resistance in populations.

MATERIALS AND METHODS

Data from three sites are reported here. Site 1 was a vineyard where glyphosate-resistant *L. rigidum* was detected in 2002. This vineyard had glyphosate applied 3–4 times per year for many years. Subsequent to the discovery of glyphosate-resistant *L. rigidum* at this site, glyphosate had continued to be used twice every year, but one glyphosate application included the addition of a dinitroaniline herbicide, either pendimethalin or oryzalin. In addition, paraquat + diquat were used in early spring in some years. Plants were collected from this site in 2005 and seed in 2006.

Site 2 was a crop margin where glyphosate-resistant *L. rigidum* was detected in 2003 under trees along a fence line. This site had received a single application of glyphosate every year for at least 15 years prior to the discovery of glyphosate-resistant *L. rigidum*. Since the discovery of glyphosate resistance, this site had been treated with glyphosate + oxyfluorfen followed by cutting the area for hay and treating any regrowth with paraquat + diquat in 2004. In 2005, the site had been treated with trifluralin followed by a late application of clethodim + quizalofop-p-ethyl. In 2006, the site had been treated with glyphosate + trifluralin + triasulfuron + oxyfluorfen followed by clodinafop-propargyl. In 2007, the site received an application of glyphosate followed a week later by an application of paraquat + diquat. Plants were collected from the site in 2005, 2006 and 2007.

Site 3 was a vineyard where glyphosate-resistant *L. rigidum* was detected in two separate blocks in 2004. Both blocks had a long history of glyphosate use. Since glyphosate resistance was detected, both sites had received two to three applications of a high rate of glyphosate + carfentrazone-ethyl each winter. Plants were collected in 2005 and 2006 from this site and seed in 2004 and 2007.

Where plants were collected, they were pulled from the field and tested for resistance to glyphosate using the Syngenta Quick Test (Boutsalis 2001). The roots and shoots of plants were trimmed and planted into potting mix. Plants were treated with glyphosate at 450 g a.e. ha^{-1} using a laboratory sprayer seven days later. Plants were assessed for survival 21 days after glyphosate application. Plants that had produced new green leaves since treatment were considered resistant, whereas those that had not were considered susceptible.

Where seed was collected, the seed was spread out on potting mix, covered with 2–3 mm of potting mix and watered. Once seedlings had reached the 3-leaf stage, they were counted and treated with herbicide as described above. Survival was assessed after 21 days as described above. In all cases, a known susceptible population (VLR 1) and the original resistant population from each site were included as controls.

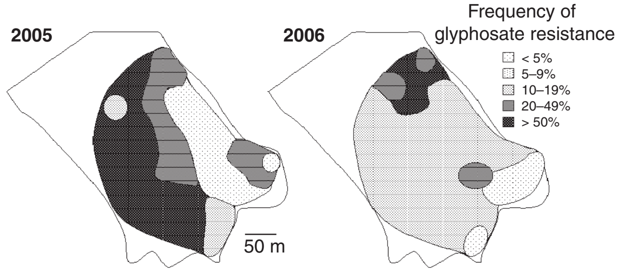

Figure 1. Distribution of glyphosate-resistant *L. rigidum* at Site 1 in 2005 and 2006.

Table 1. Frequency of glyphosate-resistant *L. rigidum* at Site 2 from 2005 to 2007.

Year	Frequency of glyphosate resistance (%)
2005	52
2006	1
2007	23

Table 2. Frequency of glyphosate-resistant *L. rigidum* at Site 3 from 2004 to 2007.

Year	Frequency of glyphosate resistance (%)	
	Block 1	Block 2
2004	50	20
2005	78	92
2006	16	6
2007	100	100

RESULTS

At Site 1, the overall frequency of glyphosate-resistant *L. rigidum* declined slightly between 2005 and 2006. However, the decline in resistance was not evenly distributed across the site with resistance declining from greater to 50% to less than 20% on the western side of the site, but increasing on the eastern side (Figure 1).

At Site 2, the frequency of glyphosate resistance across the whole site declined between 2005 and 2007 (Table 1). There was a large reduction in resistance detected in 2006, followed by an increase in 2007. Glyphosate resistance was not evenly distributed on this site, but was concentrated in three areas (Figure 2). The distribution of *L. rigidum* at this site in 2007 showed large differences in population size across the site from less than 1 plant m^{-2} to 47 plants m^{-2}. Typically, the areas with higher densities of weeds in 2007 had no glyphosate-resistant individuals (Figure 2).

At Site 3, the frequency of glyphosate-resistant *L. rigidum* increased over time. In 2004, resistance was 50% in seed collected from block 1 and 20% for block 2. By 2007, resistance was 100% in seed collected from both blocks.

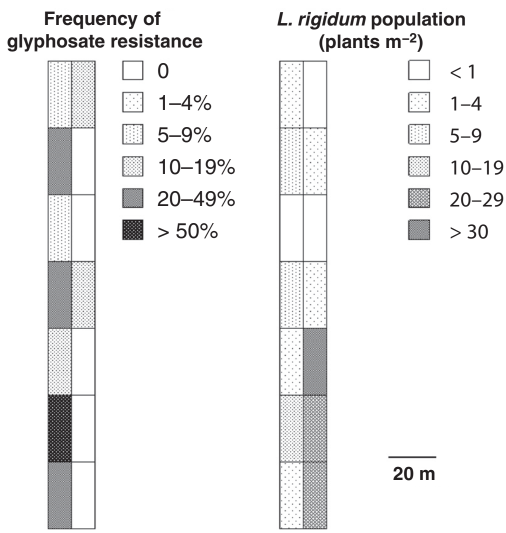

Figure 2. Frequency of glyphosate-resistant individuals (left) and population size of *L. rigidum* (right) in 30 by 10 m blocks across Site 2 in 2007.

DISCUSSION

The surveys reported here show the frequency of glyphosate resistance in farm populations of *L. rigidum* varying from year to year. There are several possible reasons for this variation including management strategies and sampling issues. Sampling issues that could affect the detection of glyphosate resistance include the size of the patches of glyphosate resistant plants, the distribution of these patches within the population and the overall size of the population. The influence of these factors was clear at Site 2, where glyphosate resistance was concentrated in a few small patches of low population density surrounded by regions of higher population density without glyphosate resistance. A second factor is the relative performance of glyphosate in the different years. Glyphosate activity on glyphosate-resistant populations can vary with environmental conditions (Powles *et al.* 1998). Therefore, overall trends should be considered rather than specific year to year comparisons.

At Site 1, the frequency of glyphosate resistance declined slightly, despite the continuing use of glyphosate on this site. However, the area infested with glyphosate-resistant *L. rigidum* had increased in size. Management at this site included the use of a pre-emergent herbicide along with glyphosate. In addition, the early application of paraquat + diquat would have reduced *L. rigidum* seed set. Given the fitness penalty associated with glyphosate resistance in *L. rigidum* (Wakelin and Preston 2006 and Preston and Wakelin 2007), these strategies may be sufficient to reduce the frequency of resistance and size of the population without reducing spread. At Site 2, the frequency of glyphosate resistance had declined and the area infested had remained small. Management at this site was intensive and directed at stopping seed set of weeds in the infested area. At Site 3, the frequency of glyphosate resistance had increased. At this site, the rate of glyphosate used had been increased substantially and carfentrazone-ethyl added. As carfentrazone-ethyl provides no control of grasses, continued selection for glyphosate resistance has occurred at this site.

Among the sites, the most effective strategies for reducing the frequency of resistance included use of effective non-glyphosate herbicides and controlling *L. rigidum* seed set. Increasing the rate of glyphosate offered the temporary ability to control more of the population, but ultimately led to an increase in the frequency of glyphosate resistance in the population.

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