Control of thiocarbamate resistant annual ryegrass (*Lolium rigidum*) in lentils (*Lens culinaris*) in southern Australia

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Summary Annual ryegrass (*Lolium rigidum*) is the most significant weed of cropping systems in southern Australia. Widespread resistance to trifluralin and post-emergent herbicides has increased reliance on thiocarbamate (group J) herbicides prosulfocarb and triallate for ryegrass control. Recent random weed surveys have confirmed resistance to thiocarbamate herbicides in South Australia, New South Wales and Victoria. A field study was undertaken in a lentil crop at Urania, South Australia in 2017 to investigate the performance of alternative pre-emergent herbicides in a population of ryegrass that had evolved resistance to prosulfocarb and triallate. Annual ryegrass density and seed production was reduced by herbicide treatments. Trifluralin did not reduce ryegrass seed set compared to the untreated. Prosulfocarb at 2400 g ha^{-1} reduced seed set by 52%, which was similar to the level of control achieved with pyroxasulfone and triallate 56% and 63% respectively. In contrast pyroxasulfone + triallate reduced seed set by 95%. Propyzamide provided the highest level of weed control, which was similar to pyroxasulfone + triallate. These results indicate thiocarbamate resistant ryegrass can be effectively managed with alternative pre-emergent herbicides.

Keywords Pre-emergent, herbicide resistance, prosulfocarb, triallate, management.

INTRODUCTION

Annual ryegrass (*Lolium rigidum* Gaud.) is a problematic weed species present in cropping fields across southern Australia with the capacity to germinate multiple times throughout autumn and winter and produce a large amount of seed. The development of wide-spread herbicide resistance in annual ryegrass has made management more difficult. Annual ryegrass control in field crops over the past 40 years has largely been through the use of herbicides. Resistance to various herbicides has increased significantly over this period including cross- and multiple resistance to diverse mode of action herbicides (Owen *et al.* 2007).

Annual ryegrass populations resistant to post-emergent herbicides has resulted in a greater reliance on pre-emergent herbicides. The pre-emergent herbicide trifluralin has been widely adopted across many parts of southern Australia with resistance detected in a large proportion of randomly collected populations (Boutsalis *et al.* 2012). The registration of prosulfocarb in 2008 provided growers with an alternative mode of action (group J thiocarbamate family), which enabled them to successfully manage trifluralin resistant annual ryegrass and was quickly adopted in medium to high rainfall environments across southern Australia. A recent survey of resistance has shown that 66% of ryegrass populations in the Mid north and Yorke Peninsula (South Australia) are now resistant to trifluralin. Similarly 78% of annual ryegrass populations in the South East are resistant to trifluralin (Boutsalis *et al.* 2012). Repeated use of group J herbicides (prosulfocarb, triallate) on trifluralin resistant annual ryegrass has increased selection pressure for group J resistance which has been reflected in some early reports of resistance. Triallate and prosulfocarb resistance was detected in a ryegrass populations on the Eyre Peninsula, South Australia in 2014. Surveys show triallate resistance present in 3% and 11% of ryegrass populations collected in Western and Southern Victoria respectively (Gill *et al.* 2016).

Evolution of resistance to group J herbicides prosulfocarb and triallate has not been widely studied in annual ryegrass. Resistance to triallate has been documented in wild oat (*Avena fatua L.*) in Canada (Beckie *et al.* 2012). Busi and Powles (2013) reported development of cross-resistance to group J herbicides triallate and prosulfocarb in a recurrently selected population of annual ryegrass. However, field evolved cross-resistance to group J herbicides has not been reported so far. This paper discusses the management options for controlling thiocarbamate resistant ryegrass.

MATERIALS AND METHODS

A replicated field trial was established in a lentil crop at Urania, Yorke Peninsula, South Australia to investigate the management of group J resistant annual ryegrass. Site selection was based on background resistance to the herbicides trifluralin, triallate, prosulfocarb and prosulfocarb + S-metolachlor and annual ryegrass density of 100–150 plants m^2. Plot size was 2 m × 10 m with four replicates in a randomised complete block design.

Lentils were sown using farmer no-till seeding equipment. A range of treatments at the recommended label rates including trifluralin, triallate, prosulfocarb, prosulfocarb + S-metolachlor, propyzamide and pyroxasulfone were applied. Herbicides were applied using a Hardi CO_2 pressurised hand operated plot sprayer equipped with T-jet 110020 nozzles spaced 50 cm apart. The sprayer was calibrated to apply 100 L ha^{-1} at 2 bar pressure at a walking speed of 3 m s^{-1}. Incorporated by seeding (IBS) treatments were applied immediately prior to seeding. Early post-emergent treatments (EPE) were applied to 2-leaf annual ryegrass.

Ryegrass and crop establishment counts were taken 28 days after IBS treatments. Ryegrass counts were taken a further 28 days after EPE treatments. Final spike counts were taken 150 days after herbicide treatments. Crop establishment counts were taken using a 50 cm rod and ryegrass counts using an 80 cm × 40 cm quadrat. Annual ryegrass spikes were also collected to calculate total seed production. Plots were not harvested for grain yield due to below-average rainfall conditions. Weather data was collected from the local Bureau of Meteorology weather station.

RESULTS

Weed density and seed production was reduced by herbicide treatments ($P<0.05$, Table 1). Herbicide treatments trifluralin, triallate, prosulfocarb, prosulfocarb + S-metolachlor and pyroxasulfone applied alone failed to provide acceptable levels of weed control (<50%) 60 days after treatment (DAT). Higher levels of weed control was achieved with propyzamide and pyroxasulfone + triallate providing 93% and 89% control respectively (Table 1). Pyroxasulfone + prosulfocarb + S-metolachlor (EPE) provided a good level of control (82%). Mixtures of products were considerably more effective compared to products alone. Prosulfocarb + S-metolachlor (EPE) resulted in poor control (59%). Prosulfocarb at 2400 g ha^{-1}, pyroxasulfone, triallate and prosulfocarb + S-metolachlor achieved poor levels of seed set reduction (<65%) 180 DAT. In contrast propyzamide and pyroxasulfone + triallate provided the highest seed set reduction (95%), which was closely

Table 1. Effect of herbicide treatments on annual ryegrass plant density and seed production in lentils grown at Urania, South Australia in 2017.

Treatment[b]	Rate (g ai ha^{-1})	Weed density[c] (plants m^{-2})	Control % (60 DAT)	Seed production[c] (seed m^{-2})	Control % (180 DAT)
		July 2017		November 2017	
Untreated	–	323 g		16,174 de	
Triallate PPI	1,500	164 cde	49	5,906 bc	63
Trifluralin PPI	1,200	343 g	0	17,878 e	0
Prosulfocarb + S-metolachlor PPI	2,000 + 300	162 cde	50	5,764 bc	64
Prosulfocarb + S-metolachlor EPE	2,000 + 300	133 cd	59	3,656 ab	77
Pyroxasulfone PPI	100	197 def	39	7,095 bc	56
Propyzamide PPI	750	24 a	93	815 a	95
Prosulfocarb PPI	2,000	280 fg	13	10,778 cde	33
Prosulfocarb PPI	2,400	265 efg	18	7,697 bcd	52
Trifluralin + triallate PPI	1,200 + 1,500	158 cd	51	6,936 bc	57
Pyroxasulfone + triallate PPI	100 + 1,500	34 a	89	788 a	95
Prosulfocarb + S-metolachlor + triallate PPI	2,000 + 300 + 1,500	93 bc	71	3,121 ab	81
Prosulfocarb + triallate PPI	2,000 + 1,500	177 cde	45	6,875 bc	58
Pyroxasulfone PPI fb prosulfocarb + S-metolachlor EPE	100 + 2,000 + 300	58 ab	82	1,310 a	92

[a] Means within the same column followed by the same letter are not significantly different according to LSD at P=0.05.
[b] Abbreviations: fb, followed by; PPI, pre-plant incorporated; EPE early post-emergent application of herbicides; DAT days after treatment.
[c] Annual ryegrass plant density m^{-2} and seed production m^{-2} data were square root transformed before mean comparisons. Data presented are the non-transformed means.

followed by pyroxasulfone followed by prosulfocarb + S-metolachlor (EPE) treatment (92%).

DISCUSSION

Development of resistance to the thiocarbamate herbicides significantly reduces the available pre-emergent herbicide options to manage these populations. Continued reliance on trifluralin in southern Australia has led to widespread resistance (Boutsalis *et al.* 2012). Management of trifluralin resistant populations has seen increased reliance on thiocarbamate herbicides (prosulfocarb) and now resistance has been detected to these herbicides. These developments highlight the risks associated with overreliance on any single mode of action herbicides (Gill *et al.* 2016). The use of newer mode of action herbicides such as pyroxasulfone in wheat and propyzamide in canola has allowed growers to manage resistant populations while rotating between other mode of action herbicides (Boutsalis *et al.* 2014). Superior weed control with pyroxasulfone and mixtures with thiocarbamates highlight the benefit of applying herbicides with different modes of action and residual activity.

Low rainfall conditions during the period of May-June in 2017 reduced the performance of pre-emergent herbicides investigated. Rainfall greatly influences herbicide behaviour (Preston 2014) and this was observed with herbicides that require rainfall post-application. In addition, the weed population at the site displayed resistance to multiple pre-emergent herbicides as previously determined through dose-response experiments. Herbicides most affected were trifluralin, triallate, prosulfocarb and prosulfocarb + S-metolachlor. Herbicides, such as pyroxasulfone and propyzamide, were also affected by the lack of early season rainfall; however, these herbicides have been successfully used to control multiple resistant ryegrass in cereal, pulse and oilseed crops respectively (Boutsalis *et al.* 2014).

Further research is required to develop effective management strategies to control thiocarbamate resistant ryegrass populations. Ineffective post-emergent options in cereals challenge growers to rely heavily on pre-emergent herbicides. Of greatest concern is management in cereals, particularly wheat where currently control of multiple resistant populations is being achieved with pyroxasulfone. Current management of multiple resistance ryegrass in pulse and oilseed crops is achieved using propyzamide. The level of crop competition from cereals in combination with a robust herbicide strategy would greatly reduce ryegrass, which currently remains a major issue in less competitive crops such as pulses. This research has shown that there are options available to growers to manage multiple resistant annual ryegrass. However, alternative management strategies such as harvest weed seed control and non-herbicide tactics would need to be introduced to avoid overreliance on remaining herbicides (Borger *et al.* 2016).

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REFERENCES

Beckie, H.J., Warwick, S.I. and Sauder, C.A. (2012). Basis for herbicide resistance in Canadian populations of wild oat (*Avena fatua*). *Weed Science* 60, 10-8.

Borger, C., Riethmuller, G. and D'Antuono, M. (2016). Eleven years of integrated weed management: Long-term impacts of row spacing and harvest weed seed destruction on *Lolium rigidum* control. *Weed Research* 56, 359-6.

Boutsalis, P., Gill, G.S. and Preston, C. (2012). Incidence of herbicide resistance in rigid ryegrass (*Lolium rigidum*) across southeastern Australia. *Weed Technology* 26, 391-8.

Boutsalis, P., Gill, G.S. and Preston, C. (2014). Control of rigid ryegrass in Australian wheat production with pyroxasulfone. *Weed Technology* 28, 332-9.

Busi, R. and Powles, S.B. (2013). Cross-resistance to prosulfocarb and triallate in pyroxasulfone-resistant *Lolium rigidum*. *Pest Managment Science* 69, 1379-4.

Gill, G.S., Boutsalis, P., Kleemann, S. and Preston, C. (2016). Herbicide resistance challenges and management strategies southern GRDC Grower and Advisor Update Adelaide 2016. School of Land, Food & Wine, The University of Adelaide.

Owen, M.J., Walsh, M.J., Llewellyn, R.S. and Powles, S.B. (2007). Widespread occurrence of multiple herbicide resistance in Western Australian annual ryegrass (*Lolium rigidum*) populations. *Australian Journal of Agricultural Research* 58, 711-8.

Preston, C. (2014). Understanding pre-emergent cereal herbicides. Grains Research and Development Corporation Update 2014. School of Land, Food and Wine, The University of Adelaide.