**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 triallulin (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 CO2 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 DA T. 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.

<table>
<thead>
<tr>
<th>Treatment⑥</th>
<th>Rate (g ai ha⁻¹)</th>
<th>Weed density⑦ (plants m⁻²)</th>
<th>Control % (60 DAT)</th>
<th>Seed production⑧ (seed m⁻²)</th>
<th>Control % (180 DAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>–</td>
<td>323 g</td>
<td>16,174 de</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triallate PPI</td>
<td>1,500</td>
<td>164 cde</td>
<td>49</td>
<td>5,906 bc</td>
<td>63</td>
</tr>
<tr>
<td>Trifluralin PPI</td>
<td>1,200</td>
<td>343 g</td>
<td>0</td>
<td>17,878 e</td>
<td>0</td>
</tr>
<tr>
<td>Prosulfocarb + S-metolachlor PPI</td>
<td>2,000 + 300</td>
<td>162 cde</td>
<td>50</td>
<td>5,764 bc</td>
<td>64</td>
</tr>
<tr>
<td>Prosulfocarb + S-metolachlor EPE</td>
<td>2,000 + 300</td>
<td>133 cd</td>
<td>59</td>
<td>3,656 ab</td>
<td>77</td>
</tr>
<tr>
<td>Pyroxasulfone PPI</td>
<td>100</td>
<td>197 def</td>
<td>39</td>
<td>7,095 bc</td>
<td>56</td>
</tr>
<tr>
<td>Propyzamide PPI</td>
<td>750</td>
<td>24 a</td>
<td>93</td>
<td>815 a</td>
<td>95</td>
</tr>
<tr>
<td>Prosulfocarb PPI</td>
<td>2,000</td>
<td>280 fg</td>
<td>18</td>
<td>10,778 cde</td>
<td>33</td>
</tr>
<tr>
<td>Prosulfocarb PPI</td>
<td>2,400</td>
<td>265 cf</td>
<td>18</td>
<td>7,697 bcd</td>
<td>52</td>
</tr>
<tr>
<td>Trifluralin + triallate PPI</td>
<td>1,200 + 1,500</td>
<td>158 cd</td>
<td>51</td>
<td>6,936 bc</td>
<td>57</td>
</tr>
<tr>
<td>Pyroxasulfone + triallate PPI</td>
<td>100 + 1,500</td>
<td>34 a</td>
<td>89</td>
<td>788 a</td>
<td>95</td>
</tr>
<tr>
<td>Prosulfocarb + S-metolachlor + triallate PPI</td>
<td>2,000 + 300 + 1,500</td>
<td>93 bc</td>
<td>71</td>
<td>3,121 ab</td>
<td>81</td>
</tr>
<tr>
<td>Prosulfocarb + triallate PPI</td>
<td>2,000 + 1,500</td>
<td>177 cde</td>
<td>45</td>
<td>6,875 bc</td>
<td>58</td>
</tr>
<tr>
<td>Pyroxasulfone PPI fb prosulfocarb + S-metolachlor EPE</td>
<td>100 + 2,000 + 300</td>
<td>58 ab</td>
<td>82</td>
<td>1,310 a</td>
<td>92</td>
</tr>
</tbody>
</table>

⑥Means within the same column followed by the same letter are not significantly different according to LSD at P=0.05.

⑦Abbreviations: fb, followed by; PPI, pre-plant incorporated; EPE early post-emergent application of herbicides; DAT days after treatment.

⑧Annual 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 pyroxasulfone + 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**


