AXIAL®, a cereal selective graminicide for the control of annual ryegrass (Lolium rigidum Gaudin) and other major grass weeds

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Summary The frequency of herbicide resistant annual ryegrass (Lolium rigidum Gaudin) has risen dramatically in Australia during recent years, with thousands of populations now resistant to Group A (acetyl-CoA-carboxylase inhibitor) and/or Group B (acetolactate synthase inhibitor) herbicides (Owen et al. 2005, Preston, unpublished data). Although resistance now predominates, it is estimated up to 4 million hectares of annual ryegrass (ARG) still remains susceptible to the cyclohexanedione (CHD), or ‘dim’, class of Group A herbicides. In 2006 Syngenta Crop Protection has released AXIAL® (100 g L⁻¹ pinoxaden), a cereal selective post-emergent graminicide belonging to the Group A mode of action. Pinoxaden has been characterised for activity on approximately 600 Australian ARG populations in both greenhouse and field studies. The results reveal that Group A resistant ARG responds to pinoxaden much like the CHD, or ‘dim’, herbicide sethoxydim. In addition, pinoxaden is likely to provide superior activity to aryloxyphenoxy propionate (AOPP) or ‘fop’ herbicides and to tralkoxydim on certain populations. For cereal grain growers still faced with Group A susceptible ARG populations, AXIAL will provide biologically and economically effective weed control as well as several additional key benefits. Pinoxaden has excellent selectivity in both wheat and barley. It is active on AOPP resistant ARG biotypes that are not CHD resistant and provides excellent control relative to the leading industry standards on, L. rigidum, Avena spp., and Phalaris spp. Therefore, whilst AXIAL® is not the solution for ARG resistance nor is a new mode of action (MOA), this should not detract from the significant benefits the product provides relative to current industry standards.

Keywords AXIAL®, pinoxaden, annual ryegrass, ARG, Lolium rigidum, Group A herbicides, resistance, cereals.

INTRODUCTION

Annual ryegrass is the most important, widespread and difficult to control weed of southern Australian broadacre farming systems (Alemseged et al. 2001). Syngenta estimates that more than 8 million hectares of Australian agricultural land are treated for the control of ARG (O’Connell and Allard, 2004).

The selective graminicide market in cereals The grass selective market in cereals is comprised of herbicides belonging to the Group A, Group B, Group D (dinitroanilines) and to a lesser extent Group E and Group K (diverse sites of action) modes of action.

Syngenta estimates that more than 2.5 million ha of Australian cropping land was treated with a Group A herbicide during 2005, representing a treatment cost in excess of AU$50 million. Cereal growers are largely reliant upon only two ACCase inhibitors, diclofop and tralkoxydim, for selective control of ARG. Diclofop is sold as a solo active ingredient and as diclofop + sethoxydim (Decision®) or diclofop + fenoxaprop (Tristar Advance®). Clodinafop is not normally used for ARG control, presumably due to the relatively high rate required and therefore high cost of treatment. Syngenta estimates indicate that for 2005 diclofop-based products were applied to over 1 million ha and tralkoxydim was applied to approximately 0.78 million ha. Despite high frequencies of resistance it is apparent growers still rely heavily on ACCase inhibitors to manage ARG.

Herbicide resistance Years of frequent use of Group A and B herbicide groups has lead to widespread resistance in ARG across the major Australian cereal cropping zones. ARG resistance is the world’s most significant case of herbicide resistance, with the weed exhibiting multiple resistance to a range of herbicide MOA (Llewellyn and Powles 2001). A recent study of the level of ARG resistance across 15 major agronomic zones in Western Australia suggested that 88% of populations had some level of resistance to the sulfonylurea Group B herbicides and 70% of populations were resistant to the Group A herbicide diclofop (Owen et al. 2005). Similarly, a study in South Australia found 74% of ARG populations were resistant to the Group B herbicide chlorsulfuron and 76% of populations were resistant to diclofop (Preston unpubl. data). Extrapolating from resistance surveys conducted in WA, SA and NSW (J. Broster unpubl. data), six million hectares of...
the Australian cereal belt is likely to be infested with herbicide resistant ARG.

In response to Group A and B herbicide resistance in ARG, farmers are also relying on Group C (photosystem II inhibitors), Group D, Group E (inhibitors of mitosis) and Group K herbicides. To date the resistance to Group A herbicides in *Avena* spp. appears to be confined to the ‘fops’ (Storrie and Cook 2002), but resistance to Group B and Group K herbicides has also been confirmed (P. Boutsalis unpubl. data).

In Australia during 2006, Syngenta Crop Protection has released, AXIAL (100 g L\(^{-1}\) pinoxaden), a cereal selective post-emergent graminicide. Pinoxaden, 8-(2,6-diethyl-4-methyl phenyl)-1,2,4,5-tetrahydro-7-oxo-7H-pyrazolo-[1,2-d][1,4,5]oxadiazepin-9-yl-2,2-dimethylpropanoate, represents a unique new phenylpyrazolin class of herbicides. It is a Group A herbicide that acts by inhibiting the enzyme acetyl-CoA-carboxylase (ACCase), interrupting the synthesis of fatty acids and subsequently impacting upon the formation of biomembranes. Pinoxaden is classified as neither a ‘fop’ nor ‘dim’ and has instead been suggested for classification as a new sub-group of Group A chemistry called the ‘den’ group (Hofer *et al.* 2005).

Given the extent of Group A resistance, it is reasonable to question the value of releasing another ACCase inhibitor into the Australian market. This paper examines the fit of AXIAL for the control of grass weeds, in particular ARG, in Australian cereals, given the extent of herbicide resistance.

**FINDINGS**

AXIAL is an emulsifiable concentrate containing 100 g L\(^{-1}\) pinoxaden (100EC) and 25 g L\(^{-1}\) cloquintocet-mexyl. AXIAL must be used with the specifically developed adjuvant ADIGOR\(^{\text{®}}\) (440 g L\(^{-1}\) methyl ester of canola oil) at 0.5% V/V for ground application or 0.5 L ha\(^{-1}\) applied via air.

Field development of AXIAL in Australia began in 2000. Over 100 small plot replicated field trials were conducted by Syngenta and independent researchers throughout the major cereal growing areas. Independent third party researchers have also conducted a series of crop tolerance trials evaluating response to the herbicide by a wide range of major cereal cultivars, including 61 varieties of wheat and 16 varieties of barley.

Trial sites were selected from commercially grown wheat and barley crops with natural infestations of the target grass weeds. Trials were subject to natural environmental variables including a severe drought in 2002.

AXIAL was compared to commercial standards applied at registered use rates. Comparisons included Topik\(^{\text{®}}\) 240EC (240 g L\(^{-1}\) clodinafop-propargyl), Achieve\(^{\text{®}}\) WG Herbicide (400 g kg\(^{-1}\) tralkoxydim), Wildcat\(^{\text{®}}\) 110EC (110 g L\(^{-1}\) fenoxaprop-p-ethyl) and Hoegrass\(^{\text{®}}\) (375 g L\(^{-1}\) diclofop-methyl). Application was made using either hand held pressurised spray boom or boom mounted on a Quad-bike. Assessments included weed control, crop phytotoxicity and grain yield.

**Grass weed control** AXIAL is registered at low use rates of 15–20 g a.i. ha\(^{-1}\) for control of *Avena* spp., 20–25 g a.i. ha\(^{-1}\) for control of *Phalaris* spp. and 25–30 g a.i. ha\(^{-1}\) for suppression of *L. rigidum* in both wheat and barley. At the recommended rate AXIAL provides control of each of the three major grass weeds at least equivalent to the industry standard, being clodinafop for *Avena* spp., fenoxaprop for *Phalaris* spp. and diclofop and/or tralkoxydim for *L. rigidum* (Figure 1).

**Characterisation of pinoxaden on ARG biotypes** In 2003, *L. rigidum* seed samples were collected at harvest from 289 paddocks across Australia (WA, SA, VIC and NSW). Commercially important grain growers were targeted, but sampling was not directed towards any particular resistance status. Samples were tested in a microscreen to characterise resistance status to the CHD herbicides AXIAL, tralkoxydim and clethodim. Three ARG standards were also included, a known sensitive, metabolic resistant and target site resistant (I1781L mutation) biotype. Herbicides were applied at four rates and tested in two replicates. Twenty-one samples were excluded from results, because of germination less than 20%. In total, 25%
of the 289 paddock samples were fully susceptible to pinoxaden. A further 42% were partially resistant and 33% were fully resistant.

A second similar study examined *L. rigidum* seed collected in a 1998 random survey of the Western Australian wheat belt. Approximately 100 of these samples were evaluated in Jealott’s Hill, UK in 2001. Standard Australian biotypes were also included. Tests involved pot trials, with five seedlings per pot and three replicates per herbicide dose. Herbicide was applied at the two leaf stage and the test evaluated a dose range of pinoxaden from 5 to 80 g a.i. ha\(^{-1}\). Also included were other herbicides at single dose: diclofop, chlorsulfuron, iodosulfuron, sethoxydim, glyphosate and sulfometuron. These herbicides were chosen to predict the possible mechanism of herbicide resistance. Surviving plants were recorded 21 days after treatment.

The study indicates that biotypes resistant to sethoxydim (indicative of ACCase target site resistance) are in most cases, but not all, resistant to pinoxaden (Figure 2). Pinoxaden controls metabolic resistant biotypes or biotypes with specific target site resistance to AOPP (Figure 3) but not CHD herbicides.

A label suppression claim for ARG reflects the fact that many paddocks infested with ARG will commonly include a percentage of the population that are resistant to Group A herbicides and ‘control’ may not be achieved in many situations. However, on known susceptible populations of ARG pinoxaden is highly effective (Table 1).

While pinoxaden activity is unlikely to be acceptable on fully resistant ARG populations, the majority of paddocks still exhibit some susceptibility to this herbicide. Therefore, on certain populations, AXIAL® is still likely to be a useful component of an integrated weed management strategy.

**Crop safety in wheat and barley** Pinoxaden provides a very high level of crop safety in both wheat and barley. This level of crop tolerance is due to both the inherent properties of the compound in addition to the inclusion of the crop safener cloquintocet-mexyl. It is known that the synthesis of herbicide degrading enzymes is selectively induced by this safener (Hofer *et al.* 2006). Tolerance studies have shown that the addition of cloquintocet-mexyl results in negligible levels of crop injury at up to four times the maximum registered Australian use rate.

**CONCLUSIONS**

Annual ryegrass is the most important grass weed of Australian broadacre farming. While many paddocks have ARG that is resistant to one or more herbicide

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<tr>
<th>Herbicide</th>
<th>Samples with response (%) control</th>
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<tbody>
<tr>
<td>Pinoxaden 30 g a.i. ha(^{-1})</td>
<td>12 18 35 37</td>
</tr>
<tr>
<td>Tralkoxydim 262.5 g a.i. ha(^{-1})</td>
<td>25 19 22 34</td>
</tr>
<tr>
<td>Clethodim 300 mL ha(^{-1})</td>
<td>3 7 40 51</td>
</tr>
<tr>
<td>Diclofop 1000 mL ha(^{-1})</td>
<td>62 11 18 10</td>
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Results from Plant Science Consulting pot tests.
modes of action (including Group A), there are still up to 4 million hectares susceptible to Group A herbicides of the CHD or ‘dim’ type. This has been confirmed by several surveys and further supported by the substantial areas treated with the cereal selective herbicides diclofop and tralkoxydim.

Cereal growers are largely reliant upon only two ACCCase inhibitors, diclofop and tralkoxydim, for the selective control of ARG in cereals. Whilst there is no doubt that both herbicides have proven to be extremely useful tools for selective grass weed control, each has its disadvantages. Activity of diclofop on Avena spp. has necessitated the need for formulation in mixtures with sethoxydim and fenoxaprop and the rapid development of AOPP resistance has also reduced the area over which diclofop is now effective. Whilst tralkoxydim still allows for effective ARG control in many circumstances, the absence of a crop safener has disadvantages in relation to crop safety, particularly in barley.

Studies with AXIAL have found it to be highly effective on the three major grass weeds Avena spp., Phalaris spp. and L. rigidum. At the recommended application rate, AXIAL will provide control of each of these weeds at least equivalent to the industry standard. Crop tolerance studies have shown that the addition of cloquintocet-mexyl results in negligible levels of injury to either wheat or barley at up to four times the maximum registered Australian use rate.

In greenhouse and field studies AXIAL outperformed the AOPP herbicides including diclofop on a large selection of ACCCase resistant ARG biotypes. Activity of AXIAL on resistant biotypes was similar to sethoxydim and tralkoxydim, but less than that of clethodim.

The widespread incidence of resistance to not only Group A but also multiple herbicide modes of action has in many instances driven the principles of integrated weed management and necessitated the adoption of a range of control measures (Powles and Mathews 1992). The need to employ a diverse range of weed management tactics in order to maximise both weed control and the longevity of herbicide performance is critical. In terms of herbicide tactics, AXIAL® is to be recommended in a program with ARG active pre-emergent herbicides belonging to the Group D, Group E and Group K herbicide groupings.

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REFERENCES