Annual ryegrass (**Lolium rigidum**) is Australia’s most economically damaging crop weed (Yu, Cairns & Powles 2004). A heavy infestation of 200 plants/m² can cause a 50% yield loss in wheat costing $100-$250/ha (Wu et al. 1998). Surveys across southern Australia found annual ryegrass in 86% of canola crops (Lemerle et al. 1999) and 69% of cereal crops (Lemerle et al. 1996). It is a primary weed of cropping systems in the Murrumbidgee catchment. Figure 1 shows an annual ryegrass plant.

**Legislation**

Annual ryegrass is not declared noxious in the Murrumbidgee catchment.

**Taxonomy**

Annual ryegrass belongs to the Poaceae (grass) family and the *Lolium* L. genus, of which there are five species in Australia. It is also known as ryegrass and Wimmera ryegrass. Other weed species in the same family include wild oats (*Avena fatua*), brome grass (*Bromus* spp.), barley grass (*Hordeum leporinum*), phalaris (*Phalaris* spp.) and silver grass (*Vulpia bromoides*).

**Origin, Introduction to Australia and Distribution**

Annual ryegrass originated in the temperate regions of Europe and Asia and was deliberately introduced into Australia as a pasture species around 1880 (Kloot 1983).

Annual ryegrass is found in all mainland states of Australia except the Northern Territory (Figure 2). It is mostly found in crops, pastures and fallows, but also on roadsides and in other non-agricultural situations. It is well adapted to most soil types in the southern Australia wheat belt.

**KEY POINTS**

- Prevent seed production for several consecutive years to deplete the seed bank.
- Knowledge of the biology and ecology of annual ryegrass is essential for effective management.
- Use of an integrated weed management program will help to delay or manage herbicide resistance.
- Ensure good farm hygiene to prevent new infestations and minimise weed spread.
Biology and Ecology

Annual ryegrass is a major weed because:

- Dense stands (>100 plants/m²) produce up to 45000 seeds/m² (Cook, Moore & Peltzer 2005)
- It is highly competitive with crop and pasture species
- It can host pathogens such as the bacteria *Rathayibacter toxicus* which causes annual ryegrass toxicity (ARGT), the Ergot fungus (*Claviceps purpurea*) which contaminates grain and the Rhizoctonia fungus (*Gaeumannomyces graminis var. tritici.*) which causes take-all
- It is resistant to several herbicide mode of action (MOA) groups
- It has high genetic variability enabling it to adapt to different environments
- It has high phenotypic plasticity enabling it to reproduce under adverse conditions
- It is a wind-pollinated out-crosser
- Seeds are dormant over summer and germinate at the season break
- Southern Australia’s temperate climate is suitable for survival
- As a valuable feed source in pastures it is often left uncontrolled.

Identification

Annual ryegrass has hairless, narrow, bright green leaves that are shiny on the back of the leaf blade. The emerging leaf is rolled as opposed to folded and the base of the plant is reddish-purple, especially in seedlings (Figure 3). It has a wide ligule and long auricles. The mature plant is up to 90cm high with spikelets 30cm long containing 3-9 flowers (Figure 4). The seeds are 4-6mm long, 1mm wide and straw coloured.

Annual ryegrass can be misidentified as perennial ryegrass (*Lolium perenne*), paradoxa grass (*Phalaris paradoxa*) and lesser canary grass (*Phalaris minor*). Perennial ryegrass has 4-14 flowers per spikelet and the outer husk is half the length of the spikelet whereas annual ryegrass has 3-9 flowers per spikelet and the outer husk is the same length as the spikelet. The *Phalaris* spp. have dull, silver-green leaves and red sap whereas annual ryegrass has shiny, bright green leaves and clear sap.

Seed Dormancy

Annual ryegrass seeds are dormant for 8-9 weeks after seed set. Release from dormancy occurs following an after-ripening period and is fastest under warm, moist conditions (Figure 5). Typically, 70% of the annual ryegrass seedbank germinates at the season break. Following a late break, a greater number of seeds will germinate in the first cohort as they have had more time to lose dormancy. Some of the seedbank will lose dormancy during the season and emerge in-crop and the remainder will not lose dormancy in the first season. Typically, 99% of the annual ryegrass seedbank will germinate within 3 years of seed set however some can germinate up to 5 years after seed set (R Stanton 2007, pers. com., 1 May).

Environmental conditions during seed development influence seed dormancy. High temperatures and moisture stress during seed development result in fewer annual ryegrass seeds that weigh less and are less dormant. Changes in dormancy may also be noticed after the onset of herbicide resistance as some mechanisms of resistance (target-based...
ACCase resistance) increase the levels of seed dormancy and decrease germination levels (Vila-Aiub et al. 2005).

**Germination and Emergence**

Annual ryegrass emergence is usually protracted, occurring from late autumn to early spring. Early cohorts have a big impact on crop yield whereas those that germinate after the crop seed are poor competitors and less likely to affect crop yield.

The optimum temperature for germination is 11°C for buried seeds and 27° for surface seeds (Cook, Moore & Peltzer 2005). Buried seeds germinate faster than those on the soil surface with the optimum position being 2cm deep. Below this, the germination rate decreases as seed depth increases, ceasing at 11-14cm, however these seeds can still germinate if brought up to 2cm (Gill 1996b). Complete loss of viable seeds can occur after 2 years burial at 10-15cm (Cheam & Lee 2005).

**Flowering**

Annual ryegrass does not require strict environmental conditions for flower initiation therefore it flowers uniformly and can adapt to short and variable growing seasons.

**Seed Production and Dispersal**

Annual ryegrass can produce 45000 seeds/m² (Gill 1996a) or 1000 seeds/plant (Stanton et al. 2002). The seeds are held tightly to the flower stem but once removed are very light and readily transported by wind, water and animals, in fodder and grain and by machinery and vehicles.

**Management**

The increasing availability of selective herbicides over the past few decades has seen herbicides become the most common form of annual ryegrass control in Australian cropping systems. The advantages of herbicides have caused over reliance and high selection pressure resulting in widespread herbicide resistance. The sustainability and profitability of our farming systems now depends on integrated weed management incorporating a range of chemical, cultural and biological weed control techniques and a proactive approach to weed management (Table 1).

Table 1. Techniques for annual ryegrass control and their effectiveness (Cook, Moore & Peltzer 2005).

<table>
<thead>
<tr>
<th>Tactic</th>
<th>Likely control (%)</th>
<th>Control range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning residues</td>
<td>50</td>
<td>0-90</td>
</tr>
<tr>
<td>Mouldboard ploughing</td>
<td>95</td>
<td>80-99</td>
</tr>
<tr>
<td>Autumn tickle</td>
<td>15</td>
<td>0-50</td>
</tr>
<tr>
<td>Cultivation</td>
<td>60</td>
<td>0-90</td>
</tr>
<tr>
<td>Knockdown herbicide</td>
<td>80</td>
<td>30-95</td>
</tr>
<tr>
<td>Double knockdown</td>
<td>95</td>
<td>80-99</td>
</tr>
<tr>
<td>Pre-emergent herbicide</td>
<td>70</td>
<td>50-90</td>
</tr>
<tr>
<td>Selective post-emergent herbicide</td>
<td>90</td>
<td>80-95</td>
</tr>
<tr>
<td>Spray topping with selective herbicide</td>
<td>80</td>
<td>60-90</td>
</tr>
<tr>
<td>Crop topping with non-selective herbicide</td>
<td>70</td>
<td>50-90</td>
</tr>
<tr>
<td>Silage and hay production</td>
<td>80</td>
<td>50-95</td>
</tr>
<tr>
<td>Pasture spray topping</td>
<td>80</td>
<td>30-99</td>
</tr>
<tr>
<td>Manuring crops and pastures</td>
<td>90</td>
<td>70-95</td>
</tr>
<tr>
<td>Grazing in pasture</td>
<td>50</td>
<td>20-80</td>
</tr>
<tr>
<td>Enhance crop competitive ability</td>
<td>50</td>
<td>20-80</td>
</tr>
</tbody>
</table>

**Chemical Options**

Herbicide resistance developed rapidly in annual ryegrass because of high genetic variability, high fecundity and reproduction by outcrossing (cross pollination by wind allows gene transfer from resistant to susceptible individuals via pollen). There are now annual ryegrass populations resistant to almost all herbicides available for its control. It is estimated that 40% of cropped paddocks in Australia contain herbicide resistant annual ryegrass (Matthews et al. 1996). Typically 20% of an annual ryegrass population is herbicide resistant before it is noticed by the landholder (R Stanton 2007, pers. com., 1 May).

A 2003 survey of South Australia found 76% of annual ryegrass populations are resistant to group A herbicides, 75% to group B herbicides and 49% to group D herbicides with multiple resistance and cross resistance common (Boutsalis 2006). There are 58 confirmed glyphosate resistant populations in Australia (Preston 2007) and paraquat resistant populations are expected to develop as its use increases where there is resistance to glyphosate. The Charles Sturt University herbicide resistance testing service receives samples from 18% more regions each year indicating resistance in new areas or more awareness of the problem.
**Herbicide Tolerant Crops**

Herbicide tolerant crops such as triazine tolerant (TT) canola and imidazolinone tolerant (Clearfield®) wheat and canola allow the use of herbicides from different mode of action groups.

**Pre-emergent Herbicides**

Non-selective and selective pre-emergent herbicides are available for annual ryegrass control in a range of crops.

<table>
<thead>
<tr>
<th>Herbicide regime</th>
<th>Probability of glyphosate resistance developing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glyphosate every year</td>
<td>0.64</td>
</tr>
<tr>
<td>Alternate glyphosate and paraquat</td>
<td>0.35</td>
</tr>
<tr>
<td>Paraquat following in-crop glyphosate</td>
<td>0.46</td>
</tr>
<tr>
<td>Double knock</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Early Post-Emergent Herbicides**

Annual ryegrass should be controlled prior to the 3 leaf stage as competition with the crop occurs from the 2 leaf stage and is not overcome by control at late tillering. Removing annual ryegrass at the 2 leaf stage, late tillering and not at all resulted in a wheat grain yield of 510, 365 and 278kg/ha respectively (Smith & Levick 1974). The yield penalty was due to decreased ears/m², grains/ear and grain weight.

**Late Post-Emergent Herbicides**

Spray-topping (selective herbicide applied at the reproductive stage of wild radish) and crop-topping (non-selective herbicide applied at physiological maturity of the crop) can reduce seed set by 95% and 90% respectively (Matthews 1996; Walsh & Powles 2006). The optimum time for crop-topping is when most annual ryegrass seed heads have just flowered. Glyphosate (450g/L) is most effective when applied to annual ryegrass at anthesis at a rate of 0.5-1.0L/ha (Steadman et al. 2006). Sprayseed® is most effective when applied during the milk and early dough stages (post-anthesis) at a rate of 0.5-1.0L/ha (Steadman et al. 2006). The ryegrass seeds produced following both treatments were smaller and the plants produced had a slower growth and reduced biomass. In addition, the number of seeds exhibiting dormancy was reduced following the glyphosate treatment.


The double knock strategy (applying glyphosate followed by paraquat) can slow the development of herbicide resistance (Table 2). It is especially useful for growers who rely heavily on glyphosate and have a high risk of developing glyphosate resistance. A robust rate of each chemical must be used.

**Cultural Options**

**Grazing**

Late spring grazing can reduce annual ryegrass seed production by 95% (Pearce 1975). Grazing as a management option should achieve a net reduction in seed returned to the seed bank every year. The seed heads are preferentially grazed by both sheep and cattle however it is critical to graze prior to seed maturity.

Using grazing as a management tool relies on the mature seed being destroyed during digestion. Stanton et al. (2002) found 10.8% of annual ryegrass seed ingested by sheep was excreted with 3.9% of this being germinable while 32.8% was excreted by cattle with 11.9% remaining germinable. Reinfestation can be prevented by a clean out period of 10 days before moving stock to a new area or feeding stock under feedlot conditions.

**Burning**

Burning can kill 99% of annual ryegrass seeds if the temperature is 400°C for 10 seconds or 250°C for 60 seconds. Burning narrow windrows (500mm-600mm wide) is more effective than standing stubble as the concentrated fuel load produces a longer, hotter burn. Emergence of weeds the following season was 18% under burnt standing stubble and 1% under burnt narrow windrows (Walsh & Chitty 2005). Burning only the windrows reduces the erosion risk as approximately only 10% of the paddock is being burnt but a large number of seeds may be outside the windrows therefore not burned.
Shallow cultivation prior to sowing increases germination and establishment of annual ryegrass in light soils. The larger initial cohort that results can then be controlled with non-selective herbicides prior to sowing. A trial in Western Australia showed only 37% of the seedbank remained following an autumn tickle compared to 69% without cultivation (Murphy, Craddock & Peltzer 2000). In heavy soils, germination is greatest when undisturbed.

Tillage equipment affects seed distribution in the soil profile and germination (Figure 6). Tillage implements which give little soil disturbance (discs such as the Day-Break or K-Hart) leave more seeds on the soil surface and have a lower level of weed germination than those which give a high level of soil disturbance (wide point implements such as the Ribbon Seeder) (Chauhan et al. 2004).

Soil inversion with a mouldboard plough can reduce annual ryegrass numbers by up to 95% as seed viability decreases (due to seed decay) with increasing depth of seed burial (Peltzer, Minkey & Walsh 2005). This practice is recommended only every 8-10 years with conservation tillage practised in between. An alternative is burying the windrow only which can reduce annual ryegrass numbers by 99% and increase wheat grain yield by 200% on suitable soil types (Peltzer, Minkey & Walsh 2005).

Delayed sowing of a crop to allow the use of a knockdown herbicide is most effective in areas with a longer growing season or where an early break occurs. Compared to other weed species, it is less effective for annual ryegrass control due to its protracted emergence pattern. If used, delayed sowing should be used with a double knockdown and be aware of the yield penalty for sowing outside the recommended window.

Crop Species, Cultivar and Density

Competitive crops can reduce annual ryegrass seed set. Peas and lupins are the least competitive species followed by barley, wheat, canola, triticale, rye and oats. There is little evidence of varietal differences in any crop.

Narrow row spacings (19cm) and high sowing rates can reduce the biomass and seed set of annual ryegrass, improve the crops competitive ability and increase crop yield by as much as 90% (Table 3) (Murphy, Craddock & Peltzer 2000; Wallace 2001; Walsh & Powles 2006).

Field peas provide several opportunities for annual ryegrass control. They can be sown later (in suitable areas) allowing the use of a knockdown herbicide prior to sowing, a high rate of trifluralin can be applied pre-sowing, metribuzin can be applied post-sowing pre-emergent and they are well suited to crop topping with gramoxone. Field peas can also be cut for hay.

Forage Legumes

Including a 3 year legume pasture phase in your rotation is financially competitive with continuous cropping (using a model), especially where herbicide resistance is present (Monjardino, Pannell & Powles 2004). The more time a paddock is out of crop the lower the annual ryegrass population when the paddock is returned to crop (Roy 2005).

Legumes with high biomass and leaf area (determined by species and sowing rate) are capable of reducing annual ryegrass growth in the first 6 weeks after emergence. Balansa clover and berseem clover were more effective at reducing annual ryegrass biomass than vetch, sub clover and murex medic at Wagga (Dear et al. 2006).

Sowing tetraploid ryegrass as a pasture species can help to control herbicide resistant annual ryegrass. Annual ryegrass is diploid (2 sets of chromosomes) however there is also a commercial variety of tetraploid ryegrass with greater seed size and vigour. When a tetraploid crosses with an herbicide resistant diploid individual a sterile triploid will be produced, reducing herbicide resistant seed set thus overall proportion of resistant individuals in the population. Tetraploid ryegrass will need to be controlled in the following cropping phase.
Harrowing

Harrowing immediately after crop emergence can reduce ryegrass numbers in cereal crops however this is only practised to a small extent in the Murrumbidgee catchment. Precision equipment may increase the practicality of removing seedlings after emergence.

Hay and Silage Making

Cutting a paddock for hay or silage prevents annual ryegrass seeds entering the seed bank provided it is done prior to seed maturation and regrowth is controlled. It can reduce annual ryegrass emergence the following season by 84% (Reeves & Smith 1975). The economic value of hay and silage production needs to be considered.

Green Manuring

Green manuring (incorporating green crops into the soil) prevents weed seed set however the economic loss in that year needs to be considered.

Fertiliser

The ability of wheat to use nitrogen effectively decreases from the 3 leaf stage which is when the ability of annual ryegrass to do so increases. Sufficient nitrogen prior to the 3 leaf stage of wheat enhances its competitive ability with annual ryegrass.

Cover Cropping/Brown Manuring

Spraying a cover crop or pasture with a non-selective herbicide the year before cropping can be used to control annual ryegrass seed set. Although brown manuring has an economic loss in the year in which it is done, the following year is more profitable (Table 4).

Table 4. A comparison of wheat yield, gross margin and in-crop ryegrass population following wheat or brown manure the previous year in Western Australia (Roy 2005).

<table>
<thead>
<tr>
<th>Site</th>
<th>Previous year</th>
<th>Yield (t/ha)</th>
<th>Gross margin ($/ha)</th>
<th>In-crop ryegrass (plants/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Wheat</td>
<td>3.27</td>
<td>377</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Brown manure</td>
<td>3.34</td>
<td>399</td>
<td>53</td>
</tr>
<tr>
<td>1b</td>
<td>Wheat</td>
<td>3.00</td>
<td>341</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>Brown manure</td>
<td>3.99</td>
<td>526</td>
<td>24</td>
</tr>
<tr>
<td>2a</td>
<td>Wheat</td>
<td>1.53</td>
<td>-17</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Brown manure</td>
<td>2.54</td>
<td>180</td>
<td>18</td>
</tr>
<tr>
<td>2b</td>
<td>Wheat</td>
<td>1.75</td>
<td>-64</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Brown manure</td>
<td>2.08</td>
<td>84</td>
<td>8</td>
</tr>
<tr>
<td>Mean</td>
<td>Wheat</td>
<td>2.39</td>
<td>159</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>Brown manure</td>
<td>2.99</td>
<td>297</td>
<td>26</td>
</tr>
</tbody>
</table>

Seed Catching

Trailing chaff carts (eg the “Chafftop”) remove up to 85% of annual ryegrass seeds (Walsh & Powles 2006). Alternatively, a trailing baler can be used where all material goes directly into the baler attached to the harvester. Up to 95% of annual ryegrass seed entering the harvester can be collected using this method (Walsh 2003). The “Rotomill” processes chaff material, destroying weed seeds as it exits the harvester. Another alternative is the larger capacity cagemill.

Disadvantages of this strategy include a significant amount of seed being shed prior to harvest that cannot be collected, logistics of handling bales, nutrient removal and no market for the bales.

Farm Hygiene

Follow good farm hygiene practices at all times to minimise the risk of new infestations and spread of annual ryegrass. For example, fodder should be fed out in a confined area as hay and grain is often contaminated with weed seeds, only clean crop seed from areas free of annual ryegrass should be sown (check analysis certificates, keep purchase records and be careful when retaining seed), maintain weed-free fence lines and other non-crop areas (eg water courses and around trees), thoroughly clean down machinery after being in infested areas and quarantine new livestock for 10 days as viable seeds can pass through sheep and cattle.

Resistance Testing

The Charles Sturt University herbicide testing service can be used to confirm resistance if it is suspected. Contact (02) 6933 4001.

RIM (Ryegrass Integrated Management)

RIM is a resistance management program used as decision support tool for annual ryegrass management. It assesses the likely biological and economic impacts of control strategies by simulating the effects on seed numbers and economic turnover. Multi-species RIM, incorporating wild radish (Raphanus raphanistrum), is also available. For more information contact your local adviser or Robert Barrett-Lennard (rbl@cyllene.uwa.edu.au).
Biological Options

A fungal pathogen (*Pyrenophora semiinperda*) has been isolated and identified as a potential bioherbicide for grass weeds in the future. The fungus infects the seed, reducing germination, emergence and seedling vigour.

Seed predation by ants is highly variable (0-100% control) and is affected by tillage, residues, soil type and proximity to refuges.

Allelopathy

The allelopathic effect of wheat can reduce annual ryegrass seed germination by 4.2-73.2%, depending on the wheat cultivar (Wu et al. 1998).

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