Glyphosate resistance in awnless barnyard grass (*Echinochloa colona* (L.) Link) and its implications for Australian farming systems

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Summary Awnless barnyard grass (*Echinochloa colona* (L.) Link) is one of the top five major weeds of world agriculture (Holm *et al.* 1977). In Australia, it is a serious weed of sorghum, maize, rice and sugar cane and is a highly competitive species that is able to produce large numbers of seeds. It can germinate on stored soil moisture then grow rapidly making timing of control critical.

A glyphosate resistant population of awnless barnyard grass in northern NSW has been confirmed. This has major implications for the management of summer fallows and weed control in summer crops. Northern NSW and Queensland farmers have adopted reduced-tillage to store soil moisture for reliable yields. A reliance on glyphosate for knockdown control of weeds in fallow has ensued with sometimes up to five applications. The development of glyphosate resistance could increase fallow control costs by $50 ha^{-1} per application. This stresses the need for the prevention of resistance in barnyard grass rather than management. A range of effective fallow and in-crop chemical treatments have been identified, broadening the options available.

Keywords Awnless barnyard grass, glyphosate resistance, reduced tillage, paraquat, moisture stress.

INTRODUCTION

In Australia, awnless barnyard grass (*Echinochloa colona* (L.) Link) is a major weed of all summer grown crops, summer fallows and can also establish and set seed in winter crops during the spring. This species is rapidly developing resistance to glyphosate and a number of other herbicide modes of action (MOAs) in both Australia and overseas. Glyphosate resistance was confirmed in 2007 in one population of awnless barnyard grass in northern NSW (Cook *et al.* 2007). A population of awnless barnyard grass from the same area was confirmed to be highly resistant to atrazine in 2004 (O'Donnell 2004). This weed is known to be resistant to four other MOAs in rice culture in Central America (Heap 2007).

Australian farming systems are largely reliant on glyphosate for the control of most weeds, including awnless barnyard grass. Glyphosate is used extensively in the fallow or non-crop phase of the cropping sequence. Widely adopted reduced-tillage farming systems rely heavily on herbicides to control weeds, especially glyphosate as a pre-plant knockdown. The introduction and adoption of glyphosate-resistant crops such as cotton further increases glyphosate reliance, where the system is designed for almost exclusive glyphosate usage.

This paper discusses the agronomic characteristics of awnless barnyard grass, the farming systems contributing to glyphosate resistance and suggests optimal enterprise sequences for various scenarios.

DISCUSSION

Agronomic characteristics Awnless barnyard grass produces up to 42,000 seeds plant^{-1} (Mercado and Talatala 1977) and can have densities of over 3000 plants m^{-2} in fallows. Fresh seed exhibits innate dormancy delaying germination to the following season and the burial of seed increases its survival and persistence (Wu *et al.* 2004). After six months burial, seed survival was 19%, 23% and 46% at 0–2 cm, 5 cm and 10 cm respectively. Environmental stress also appears to induce a level of dormancy.

Awnless barnyard grass will germinate from late September to April. On red clay loams, significant germination occurs after 10 mm of rain, while heavier clay soils require 20–30 mm. It often germinates on stored soil moisture necessitating control even when no rain falls. In northern NSW, it is common for farmers to spray summer fallows every 5–6 weeks regardless of rainfall (Penberthy pers. comm.).

Flowering and seed production occurs mainly in summer and autumn and seedling growth is rapid. Awnless barnyard grass can produce a spreading rosette depending on available light and competition with other plants. It is a highly competitive and fast growing species (Holm *et al.* 1977).

The rapid growth of awnless barnyard grass makes timing of control critical. The application of the contact herbicide paraquat (600 g a.i. ha^{-1}) gave 96% control of 2–3 leaf awnless barnyard grass (Storrie *et al.* 2006). Control declined to 75% eight days later when the grass was tillering and 6–10 cm in diameter.

Awnless barnyard grass can exhibit moisture stress quickly, greatly reducing the level of control by herbicides. Wicks *et al.* (1993) showed that the effective rate of glyphosate increased quickly with the size of the plant and the level of moisture stress, with 900 g a.i. ha^{-1} glyphosate controlling less than 70% of tillered plants. Moisture stress increased the rain-fast period for glyphosate up to 22 hours compared to six hours on the label. This has major implications for barnyard grass control in areas with summer storms.

Exacerbating these problems and lowering levels of control are poor spray conditions such as high Delta T (a measure of humidity-temperature interaction), poor quality water used for spraying and antagonism between tank-mix partners such as when glyphosate is mixed with 2,4-D to broaden the weed spectrum.

Farming systems where awnless barnyard grass has developed glyphosate resistance Northern NSW has a variable rainfall distribution which can normally be described as 50% summer and 50% winter. The area where the resistant population has evolved receives an average of 570 mm per annum with 200 mm in winter crop, 280 mm in summer crop and 90 mm falling between crops. Summer rainfall usually occurs with high intensity storms and summer fallows are used to store soil moisture for the next crop.

A typical rotation consists of winter pulse – summer fallow – winter cereal – summer + winter fallow – summer sorghum – winter + summer fallow – winter cereal. This gives three summer fallows in five years. On average the enterprise split is 20% long fallow cereal, 20% summer crop, 20% winter pulse, 20% short fallow cereal and 20% fallow. The most common winter cereal is wheat and the most common winter pulse is chickpea while sunflower or dryland cotton are sometimes substituted for sorghum.

Another common rotation is wheat – summer + winter fallow – summer sorghum – winter + summer fallow – wheat – summer fallow. This gives three summer fallows in four years.

In both systems there is a high proportion of summer fallow with significant summer rainfall where glyphosate is the primary weed management tool, especially for grass weeds.

Managing glyphosate-resistant barnyard grass Prevention of glyphosate resistance developing in populations of awnless barnyard grass is the preferable option for farmers. This should be possible with the introduction of a wide range of management options aimed at 100% seed set control in summer fallow, accompanied by increased monitoring for weed control. The introduction of non-glyphosate knockdown herbicides will be essential but will come at an estimated increased cost of \$5–50 ha^{-1} per application. These should be combined with residual herbicides such as imazapic or a triazine in the summer fallow prior to the winter pulse crop, to reduce the selection pressure on the knockdown component. Opportunistic cropping with short-season summer pulse crops such as mung beans planted on narrow rows should provide the benefit of crop competition combined with Group B MOA pre-emergent herbicides, Group A selective grass herbicides in-crop and the potential for pre-harvest crop desiccation with diquat.

Once glyphosate resistance has developed, fewer options are available to farmers. Cook *et al.* (2008) reported 95–98% control of awnless barnyard grass with 10 L ha^{-1} glyphosate (450 g a.i. L^{-1}) which often has plant densities between 500 and 1000 plants m^{-2}. However, 2% survival still means 10–20 plants m^{-2} remaining to set seed.

To obtain near 100% awnless barnyard grass control in fallow, the double knock technique needs to be used. Glyphosate followed by a bipyridil herbicide five days later gave 100% control (Table 1), while glyphosate or bipyridil alone gave 90–99% (Cook *et al*. 2007).

Due to the rapid growth rates of awnless barnyard grass, the time between herbicide applications should be no longer than five days. It is likely that a single application of bipyridil alone will be insufficient to

Table 1. Control of 1–2 leaf glyphosate-resistant awnless barnyard grass (*E. colona*) using knockdown herbicides (450 g L^{-1} glyphosate, 250 g L^{-1} paraquat 135 g L^{-1} paraquat + 115 g L^{-1} diquat). Data are means of three replicates.

Herbicide		Rate	Control
Time 1	Time 2[A]	(L ha^{-1})	(%)
glyphosate		1.5	90
glyphosate		2.0	95
	paraquat	2.4	99
glyphosate	paraquat	1.5 + 2.4	100
glyphosate	paraquat + diquat	1.5 + 2.4	100
LSD (P = 0.05)			2.4

[A] Time 2 is 5 days after Time 1.

give 100% control. However work with glyphosate resistant annual ryegrass (*Lolium rigidum*) has shown that two consecutive bipyridil applications can give better control than glyphosate followed by a bipyridil (Storrie 2005).

It is recommended that grain sorghum or other summer grass grain crops not be grown until barnyard grass seed banks are reduced to very low levels. Wu *et al.* (2004) found that the highest level of grass weed control in sorghum on 1 m rows, under ideal conditions, was 88% recorded 95 days after treatment with atrazine. Often dry weather during crop establishment greatly reduces the efficacy of atrazine and metolachlor. Once a crop is established, it would be difficult to convince many growers of the benefits of removing the crop for weed control.

Cultivation should largely be avoided due to the burial of seed increasing seedbank life. However research conducted by Douglas and Peltzer (2004) demonstrated that a 'one-off' deep burial of annual ryegrass seed with a mouldboard plough reduced weed emergence by over 95% and had the effect of resetting the weed seedbank. This concept could be effectively used to bury glyphosate-resistant barnyard grass seedbanks, especially if combined with soil amelioration or nutrient redistribution.

Quarantine is particularly important with glyphosate resistance as it is rare and difficult to develop. There is a high risk of moving or spreading seed via machinery if quarantine is not properly completed. Grazing infested paddocks is not recommended due to the potential for seed movement to new areas on hooves, hides and in faeces.

Another area where resistant barnyard grass populations can increase is in winter crops in late spring. Spring rain may stimulate barnyard grass germination under the crop canopy which will then set seed before crop harvest. Regular crop inspections after rain followed by desiccation with a bipyridil herbicide are recommended.

The rapid adoption of integrated weed management (IWM) principles in areas receiving summer rainfall and irrigation is essential for preventing the development of glyphosate resistant summer weeds. Further research on resistant populations to demonstrate the benefits of IWM is planned.

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