MANAGING HERBICIDE RESISTANT ANNUAL RYEGRASS, SOUTHERN AUSTRALIAN RESEARCH

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Summary Multiple herbicide resistance in *Lolium rigidum* can extend to all of the commonly used selective herbicides, such that control by selective herbicides in many cropping systems is difficult. The widespread appearance of multiple resistance has forced the adoption of integrated non-chemical strategies for control of *L. rigidum*. The reduction of *L. rigidum* density has been investigated in cultivation systems and in IWM systems experiments. The implementation of delayed crop seeding, planting of competitive crop species and catching weed seed at harvest in conjunction with the use of non-selective herbicides to minimize *L. rigidum* was examined in experimental crop rotations in South Australia. The integration of these IWM techniques will enable successful management of the thousands of populations of multiple herbicide resistant *L. rigidum*.

INTRODUCTION

Lolium rigidum (Gaud.) is a widespread and economically important annual weed of the cropping regions of southern Australia. *L. rigidum* is a highly fecund, adaptable and competitive winter growing annual which infests cereal and dicot crops. It is an allogamous species, therefore substantial genetic variability is present in all populations. Since the first report of Heap and Knight (1988, 1982), thousands of separate populations of herbicide resistant *L. rigidum* have evolved because of the frequent use of selective herbicides to control this weed. A survey of *L. rigidum* infestations within cropped fields in an intensively cropped area of about 8000 km^2 in South Australia in 1994 revealed that 40% of all fields surveyed contain diclofop methyl resistant populations (Nietschke *et al.* 1996). A telephone survey in 1991 indicated that 4000–5000 farms across southern Australia had herbicide resistant populations.

Resistant populations have been rapidly selected by herbicide use from the high frequency of genes conferring resistance to herbicides present in 'natural' *L. rigidum* populations. Studies of populations of *L. rigidum* with no history of herbicide use have shown that initial frequencies of resistant individuals can be up to 2.0% in some environments (Matthews and Powles 1992). Such a high frequency of 'background' resistance explains the rapid development of thousands of resistant populations over such a large area.

The rate of development of resistance within *L. rigidum* populations can be rapid. Where the selection pressure has been consistent, high levels of resistance have occurred within four or five years (Gill 1995, Tardif *et al.* 1993, Matthews unpublished). This is about the expected rate of development where resistance is inherited as a single dominant gene. In both established and newly selected cases of herbicide resistance studied so far in *L. rigidum*, the resistance to the group A and B herbicides have been shown to be inherited with a high level of dominance (Tardif *et al.* 1996, Matthews unpublished).

An important difference between *L. rigidum* and other herbicide resistant weeds is the development of complicated patterns of resistance in many of the reported cases. Many of the populations tested from southern Australia exhibit multiple resistance and/or non-target site cross resistance (Preston *et al.* 1996, Powles and Matthews 1992) and differences in the response to different selective agents have been seen (Gill 1995). The occurrence of multiple and cross resistance is now accepted for *L. rigidum* and many of the resistant populations are routinely tested to determine the extent of multiple resistance.

Multiple resistance in *L. rigidum* occurs as a result of herbicide use selecting for any resistance mechanisms capable of protecting a plant from the applied rate of herbicide when herbicide selection is initiated (Powles and Matthews 1992). As *L. rigidum* is a preferentially allogamous species, the diversity of biochemical mechanisms conferring resistance to herbicides which are present in natural populations are introgressed into other plants surviving the herbicide application. Thus, a combination of biology, genetic variability and herbicide application regimes means that populations have a high risk of developing resistance to a range of herbicides.

INTEGRATED WEED MANAGEMENT FOR CONTROL OF *L. RIGIDUM*

Management of multiple herbicide resistant populations can be difficult, especially in areas where continuous crop production is the favoured land use. Due to the diversity of resistance occurring in *L. rigidum* successful long-term management of multiple herbicide resistant *L. rigidum* cannot be achieved by changing herbicides. There are no selective herbicides available which can control all of the resistant biotypes and due to multiple or cross-resistance, alternative selective herbicides have had a limited use life if used exclusively on the resistant biotypes. However, herbicide use targeted at *L. rigidum* is still common as many farmers perceive that utilizing the remaining herbicides to be a more economical approach than integrated non-chemical weed control measures.

There is little likelihood of the proportion of resistant plants decreasing in the absence of herbicide application as there have been no physiological or fitness differences identified between resistant and susceptible populations (Gill *et al.* 1996, Matthews and Powles unpublished). Control of multiple herbicide resistant *L. rigidum* therefore requires a management program which successfully integrates appropriate non-herbicidal control techniques.

Integrated weed management (IWM) is the planned and managed use of physical, chemical and biological measures to control specific weeds or weed populations. Successful IWM for multiple herbicide resistant *L. rigidum*, or indeed any pest species, depends on understanding and exploiting particular biological characteristics of the species and its dynamics within the agro-ecosystem.

Table 1. Effect of a three week delay of seeding on the number of mature *L. rigidum* plants in crop and on the following seedbank.

	L. rigidum (m^{-2})			
	Early Seeding		Late Seeding	
Crop spp.	Plants	Seeds	Plants	Seeds
Peas	234	15955	104	12011
Barley	367	2240	152	1060
Wheat	419	5557	237	5791

Data are the mean of three annual counts; crop was significant ($P<0.05$) in each year and treatment significant ($P<0.05$) in two of three years.

Table 2. Effect of crop species on the number of mature *L. rigidum* plants present in the following crop and the seed bank at the end of the growing season in a wheat, barley and pea rotation.

	L. rigidum (m^{-2})	
Crop spp.	Crop sequence	Plants seeds
Wheat, barley, peas	169	13483
Peas, wheat, barley	280	1650
Barley, peas, wheat	328	5674

Data are the mean of three annual counts; crop was significant ($P<0.05$) in each year and treatment significant ($P<0.05$) in two of three years.

Research on IWM strategies has established that delayed crop seeding, seed catching, increased crop density and competitive crops as well as non-crop periods can reduce *L. rigidum* populations to below the crop damage threshold in many instances. In southern Australia some aspects of IWM have not been well researched; the interaction between increased crop density and weed competition and fecundity and also herbicide efficacy are lacking.

Delayed crop seeding date A feature of *L. rigidum* biology is the short residual life of seed in the seedbank as the majority of the seed germinates in the following growing season. The short term seedbank life and the high proportion of emergence can be exploited in IWM strategies to limit the presence of this species in winter sown crops. Early cultivation to stimulate emergence has had limited uptake in southern Australia. The effectiveness of an 'early tickle' was investigated by Davidson (1994) who found that in soils with good moisture retention, early cultivation reduced the early emergence and increased the subsequent weed density in crop. Delaying crop seeding until after the peak of *L. rigidum* emergence enables control of seedlings by cultivation or the use of non-selective herbicides, resulting in fewer seedlings in the crop. Table 1 presents a summary of IWM experiments which shows that delayed seeding reduced *L. rigidum* plants infesting the crop by 52% and the *L. rigidum* seed bank by 21%, averaged across all treatments.

Competitive crops *L. rigidum* will reduce crop yields depending on the crop vigour, canopy structure and weed density. The vigour of crops against *L. rigidum* was ranked as oats = cereal rye = triticale > canola > wheat = barley > lupins = peas over two seasons by Lemerle *et al.* (1995). Table 2 shows that peas compete poorly with *L. rigidum* in comparison with wheat and barley when the effects of crop species are averaged across all treatments. The most sustainable method of weed control is to establish vigorous and competitive crops that will compete with weeds. There is an extensive research effort now underway to identify the most competitive wheat genotypes to further improve the competitiveness of wheat varieties against weeds (D. Lemerle, G. Gill personal communication).

Most crop production systems in southern Australia rely on a rotation of crops to maintain freedom from potentially devastating root diseases of the cereal crops. Thus the rotational phase which comprises less competitive broadleaf crops, such as peas, lupins and beans, can mitigate against the success of *L. rigidum* suppression during the more competitive cereal phases of the rotation. This can be offset to some extent by the use of pre-emergent herbicides such as trifluralin and some triazine herbicides which can be used at a higher rate in broadleaf crops than in cereal crops. However, some farmers in southern Australia have identified the legume crop phase as sensitive to weed infestation and have instigated crop-topping in pulse crops, green manure or spray-topping legume pastures as additional control practices.

Use of trifluralin pre-emergence to control *L. rigidum* in crop The use of the pre-emergent herbicide trifluralin is increasing in many areas of southern Australia. Although the long term level of population suppression offered by trifluralin is poor and there are problems with application in stubble retention systems in Australia, trifluralin can make an important contribution to an integrated approach to *L. rigidum* management. Resistance to trifluralin as a result of trifluralin use is not common, although cross-resistance to trifluralin does occur (McAlister *et al.* 1995). Trifluralin is effective on *L. rigidum* and has a low risk of developing resistance compared to the group A and B herbicides. Trifluralin use in a wheat and pea crop rotation significantly reduced *L. rigidum* plant numbers (Table 3) compared to the control treatments but not over the course of the rotation.

Table 3. Effect of trifluralin on the *L. rigidum* seed bank, data is the mean of three years assessment following each crop in a wheat and pea rotation.

	L. rigidum (seeds m^{-2})	
Crop spp.	+ trifluralin	- trifluralin
Peas	711	2591
Wheat	287	1664

Crop, treatment and interaction significant (P<0.01) in each year.

Table 4. *L. rigidum* seed bank following crop-topping with paraquat in pea crops for three seasons.

	L. rigidum seeds (m^{-2})	
	Crop topping	No crop topping
1994	186	1021
1995	217	883
1996	1443	5451

Treatment significant in each year (P<0.01).

Table 5. Averaged effect of three years of seed catching and removal at harvest on the next season's initial *L. rigidum* seedbank.

	L. rigidum (seeds m^{-2})	
Crop spp.	With seed catching	Without seed catching
Peas	7670	21758
Barley	1231	2045
Wheat	3930	7593

Peas and wheat significant dif. in each year (P<0.05) and significant pea and wheat × catching interactions (P<0.05) in each year.

Use of non-selective herbicides to control *L. rigidum* Paraquat is registered for in-crop use in Australia to reduce viable *L. rigidum* seed at the post-anthesis stage of field peas, lupins, faba beans, chickpeas and vetch crops. Some reduction of crop yield may occur but the technique of crop-topping with paraquat has a greater effect on the grass weeds than the broadleaf crop and is usually considered to be cost effective over the duration of a crop rotation. The application of up to 150 g a.i. ha^{-1} of paraquat has been shown to substantially reduce the viability of immature *L. rigidum* seed (Matthews *et al.* 1995, Mayfield 1994). Data from our experiments show that the *L. rigidum* seedbank was reduced by an average of 79% following crop topping in a pea crop when the effect of crop-topping was averaged across years and treatments (Table 4).

Catching *L. rigidum* seed at crop harvest Most *L. rigidum* seed is held tightly within the glumes and is not immediately shed at plant maturity. Our research has identified that it is possible to reduce the amount of *L. rigidum* seed which reinfests the field by isolating the seed from crop residues and removing the weed seed from the field during the harvesting process (Matthews *et al.* 1996). Accessories for commercial harvesters are now available in Australia for this purpose, although uptake of this technology by farmers has been slow. The benefits of reaping weed seeds has been evaluated in a three crop rotation and Table 5 shows that *L. rigidum* seedbanks were reduced overall by 52% when *L. rigidum* seed was caught during the harvesting process and removed from the field to prevent reinfestation. Similar results have been reported from Western Australia.

Crop yields with IWM In the southern Australian crop producing areas there has been considerable emphasis on early seeding of crops to maximize crop yields. The use of IWM methods outlined above has not led to a decline in crop yields in our experiments when compared to herbicide treated weed free controls. For the least competitive crops in these experiments, wheat and peas, a significant increase in yield was apparent in the later seeding treatments in two of three years. Later seeding also increased wheat grain protein content. In another experiment the use of pre-emergent herbicide and crop topping gave significant crop yield improvements due to reduced weed numbers.

The use of non-selective herbicides The use of the non-selective herbicides glyphosate and paraquat as preplanting herbicides has increased as a substitute for cultivation. There is limited resistance to these herbicides in *L. rigidum* so these herbicides provide a valuable chemical tool in a control program. In addition to the use of non-selective herbicides pre-seeding, those same herbicides are often used to reduce *L. rigidum* seed set in pastures by application of a reduced rate of paraquat or glyphosate at late anthesis in the year prior to crop establishment. The practice of pasture spray-topping, can substantially reduce *L. rigidum* infestations in the following crop phase. Our experimental work has shown about an 80% decline in the *L. rigidum* seed bank following one year of pasture spray-topping and about 90% decline following two years of pasture topping.

LIMITATIONS OF IWM SYSTEMS

Grass weeds other than *L. rigidum* infest cropped areas of southern Australia. While *L. rigidum* is the most widespread weed, with the successful development of IWM systems for the control of herbicide resistant *L. rigidum*, other grass weeds will increase. Other common weeds are *Avena fatua*, *A. sterilis*, *Hordeum leporinum* and *H. glaucum*. Our research showed that these species may invaded sites where the *L. rigidum* population had been reduced by successful IWM measures. There are serious consequences from *Avena* and *Hordeum* grass weed infestations with crop yield reduction due to competition and to increasing levels of root diseases. Herbicides will increasingly be directed against these species. In the last few years, resistance to post-emergence selective herbicides has been detected in both the *Avena* species (Mansooji *et al.* 1992) and it is likely that resistance to the group A herbicides will develop in the *Hordeum* species. Thus, it seems likely that the successful implementation of IWM measures to control multiple herbicide resistant *L. rigidum* will also require increased attention to the other grassy weeds. The objective in successfully controlling *L. rigidum* by IWM must be extended to limiting the potential of other weeds to invade.

CONCLUSION

The advent of multiple resistance has had a beneficial impact as it has forced the recognition of IWM strategies which work and are cost-effective. The most far-reaching change required for successful management involves a change in attitude by growers and those that advise them. There has to be the acceptance that herbicides alone are not a sustainable weed management strategy and that IWM techniques merit adoption. Some farmers have changed their focus from a preoccupation with herbicidal control to a focus on population dynamics in managing a weed population through periods of crop and/or pasture rotation. Grower experience, and the research summarized in here show that multiple herbicide resistant *L. rigidum* can be managed within cropping systems, particularly when more than one IWM measure are combined. Herbicides remain a component of IWM strategies for the management of multiple resistant *L. rigidum*, however, successful IWM strategies utilize herbicides and a range of non-chemical control methods which suit the biology of the weed within a particular environment and crop production system.

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