Herbicide use strategies for herbicide resistance management

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Keywords

- Herbicide resistance management, ryegrass, sowthistle, resistance testing, new mode of action herbicides, weed survey, clethodim, glyphosate, growth stage, rate, formulation.

Take home messages

- Trifluralin remains an effective pre-emergence herbicide option in WA.
- Group J and K herbicides are integral part of herbicide resistance management.
- New pre-emergence herbicides with diverse modes of action are in development.
- Herbicide resistance testing can help identify which herbicides and what rates are effective.
- Glyphosate resistance is increasing with product choice, herbicide rate, weed growth stage and temperature affecting glyphosate efficacy.

Efficacy of existing post-emergent Group A and B chemistry

The GRDC funded random weed surveys of cropping regions across WA, SA, VIC and NSW have shown there are significant differences in the incidence of resistance even between cropping regions. For this reason, missed opportunities can arise if resistance to Group A and B herbicides are assumed without confirmation. With the aid of commercial resistance testing, the effectiveness of herbicides can be determined and a baseline of herbicide sensitivity established taking the ‘guess work’ out of herbicide decisions. Confirming the effectiveness of a post-emergent Group A or B herbicide can be a very important tool to control ryegrass after pre-emergence herbicides have dissipated.

Table 1: Results of a resistance test from a WA farmer conducted by Plant Science Consulting. The test has highlighted several effective herbicide options.

Herbicide	Product Rate (ml or g/ha)	Herbicide Group	Survival (%)	Resistance Rating
Verdict + 1% Hasten	85	A-FOP	70	RR
Select + 1% Hasten	250	A-DIM	20	R
Select + 1% Hasten	500	A-DIM	0	S
Hussar OD + 1% Hasten	100	B-SU	90	RRR
Atrazine + 0.2% BS1000	2000	C	0	S
Triflur X	1000	D	0	S

Clethodim: For some herbicides that have a labelled rate range, control can vary from resistance at lower rates to complete control at higher rates. One such herbicide is clethodim, an important herbicide in broadleaf crops. In some situations, however, increasing the rate does improve control. Apart from herbicide rate, the environmental conditions at application play an important role in herbicide efficacy. Clethodim efficacy increases with temperature. Application of clethodim on ryegrass stressed by frost just before or just after application can result in reduced control. It is advisable to delay the application by a further week if milder conditions are forecast.

Table 2: Control (%) of Z21 ryegrass tested with Select® and Factor® in pot trials. Seeds from farmer paddocks were germinated, grown outdoors to the 1-2 tiller stage and sprayed with herbicides. Supercharge® used with Factor, Hasten® used with Select.

Sample ID	Herbicide				
	Factor 100 g/ha	Factor 180 g/ha	Select 300 ml/ha	Select 500 ml/ha	Select* 1000 ml/ha
954	75	83	80	100	100
956	66	74	50	80	90
969	19	82	27	70	88
834	91	100	95	100	100
866	93	99	83	100	100
932	95	98	67	96	93
748	78	100	75	100	100
752	74	98	80	100	100
755	64	100	33	98	100
541	7	85	50	100	100
737	22	88	63	91	100
1212.3	40	77	69	56	100
1234.1	60	100	25	78	80
1197.2	55	85	80	100	100
1209.3	76	100	83	98	100
1174.2	21	81	40	98	100
1293	9	17	13	43	67
L300	63	93	75	98	100
L739	10	21	33	32	80

AUS93	68	100	90	100	100
Susceptible	100	100	100	100	100

*above label rate. Rate for guide only.

Outcomes from random weed surveys

The GRDC funded random weed surveys have confirmed the incidence of resistance in ryegrass. This in turn has stimulated research from both the chemical industry to develop new herbicides and research laboratories to better understand the development and management of herbicide resistance to old and new chemistry.

Resistance to pre-emergent herbicides

Pre-emergent herbicides offer alternative modes of action (MOA) to Group A and B herbicides. For this reason, use of this diverse chemistry is important. The majority of pre-emergent herbicides belong to either the Group D, J or K mode of action groups (Table 3).

Table 3: List of pre-emergent herbicides that are registered or in development.

Year	Company	Mode of action	Trade Name	Chemical name
Pre-2005	many	D	Triflur X etc.	Trifluralin
Pre-2005	many	J	Avadex etc.	Triallate
2008	Syngenta	J/K	Boxer Gold	Prosulfocarb + S-Metolachlor
2011	Bayer	K	Sakura	Pyroxasulfone
2015	Many	D	Edge etc.	Propyzamide
2017	Syngenta	J	Arcade etc.	Prosulfocarb
2017	BASF	K	Butisan-S	Metazachlor
2019	FMC	K+Q	Altiplano	Napropamide + clomazone
2019 (?)	Adama	?	AG-C4-900	?
2020 (?)	FMC	?	F9600	?
2020?	Arysta	?	ARY-452	?

Group D herbicides

The incidence of trifluralin resistance in WA in ryegrass is less than 5% compared to some regions such as northern SA where at least 50% of ryegrass collected from random weed surveys is resistant. For this reason, trifluralin remains a key weed control option in WA. Rotating with other MOA herbicides can reduce selection pressure on trifluralin and prevent further resistance. Additionally, mixtures with full rates of other herbicides such as triallate (e.g. Jetti Duo®) can reduce selection for resistance. In addition, the duration of activity can be extended since both herbicides target different phases of ryegrass germination. Propyzamide is also categorised in the Group D MOA grouping. However, propyzamide and trifluralin are chemically dissimilar and to date, no trifluralin resistant ryegrass populations have exhibited cross-resistance to propyzamide.

Group J herbicides

Triallate, Boxer Gold® (prosulfocarb + S-metalochlor) and prosulfocarb (Arcade®, Coundown® etc.) are currently registered Group J herbicides in cereals. To date there is limited information in cross-resistance between triallate, prosulfocarb and Boxer Gold. One ryegrass population (198-15) from central NSW in 2014 was not controlled with Boxer Gold (Table 4). Herbicide resistance testing confirmed resistance to field rates of Boxer Gold and triallate in pot trials. A second ryegrass population from the Yorke Peninsula (375-14) in SA was not controlled with triallate in 2014. Testing confirmed resistance to triallate but not to Boxer Gold. This suggests that control of triallate resistant ryegrass with Boxer Gold will vary. A third sample (EP162) identified in the 2014 random weed survey in the southern Eyre Peninsula was confirmed resistant to Boxer Gold and triallate but not Sakura® or propyzamide.

Cross-resistance between triallate and prosulfocarb

Cross-resistance between prosulfocarb and triallate was confirmed in a ryegrass population selected from recurrent selection of a susceptible population (Roseworthy-R) treated with a high rate of triallate in the field (Table 4). This indicates that strong selection through Group J herbicides can select for resistance and rotating between prosulfocarb and triallate should be avoided for ryegrass control.

Table 4: Survival (%) of four ryegrass biotypes to field rates of pre-emergent herbicides in a winter pot trial.

	Ryegrass biotypes					
Herbicides	EP162	198-15	375-14	SLR31	Roseworthy-R	Susceptible
Sakura	0	0	0	0	0	0
Boxer Gold	32	29	0	0	0	0
Avadex	54	43	100	0	60	0
Trifluralin	7	20	-	79	0	0

EP162: was identified from the 2014 random weed survey of southern Eyre Peninsula

198-15: identified from central NSW after poor control with Boxer Gold

375-14: identified from the Yorke Peninsula SA after poor efficacy with triallate.

SLR31: trifluralin resistant biotype
Roseworthy R: selected with high rates of triallate in a field trial from a susceptible population and resistance enriched after recurrent selection
S: a susceptible field population.

Group K herbicides:

Sakura is the only isoxazoline Group K herbicide currently registered with ryegrass the main target weed in wheat. The only other Group K herbicides registered in cropping are the chloroacetamide herbicides metolachlor and S-metolachlor although their use has been minor due to limited crop selectivity. This indicates much lower selection pressure on ryegrass with chloroacetamide herbicides than with the Group J herbicide triallate over the past three decades. In 2017, another chloroacetamide herbicide Butisan S® (metazachlor) was registered in canola for control of ryegrass making available another Group K herbicide for broadacre cropping. FMC are developing a Group K (napropamide) + Q (clomazone) pre-emergence herbicide (Altiplano®) product to be registered in 2019 for controlling ryegrass in canola. These herbicides represent a new Group K chemical class for napropamide (acetamides) and a new mode of action class (Group Q) for clomazone.

To date no resistance to Group K herbicides has been detected in field populations. The currently registered Group K herbicides have been shown to possess multiple target sites and therefore the chance of target site resistance conferring whole plant resistance is very low. Additionally, because Group K herbicides are chemically dissimilar the risk of cross-resistance between them is low.

Glyphosate resistance

Glyphosate resistance in ryegrass has been detected in random weed surveys of cropping regions across WA, SA, VIC and NSW. The incidence of resistance to glyphosate identified in these surveys has been presented in Figure 2.

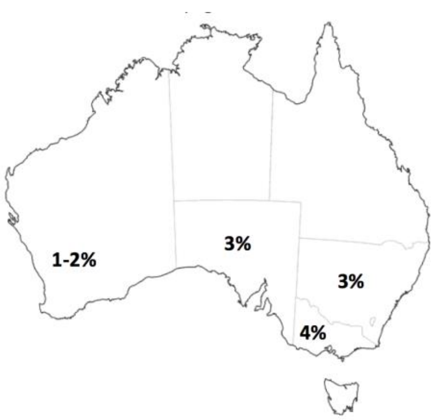

Figure 2: Incidence of paddocks containing glyphosate resistant ryegrass from GRDC funded random weed surveys. Resistance is defined as a sample where ≥20% plant survival was detected in a pot trial. Paddocks surveyed in WA = 500, SA = 700, Vic = 450 and NSW = 600.

Glyphosate resistance in ryegrass has also been detected in farmer samples sent to commercial resistance testing laboratories. In most cases, testing requests have been to identify effective herbicides or verify a herbicide failure. Requests to test with glyphosate due to poor performance is common. Figure 3 presents results from Plant Science Consulting during 2017. It highlights that the level of glyphosate resistance is similar across the southern states and is approximately 10-fold greater than the figures identified in the random weed surveys (Figure 2).

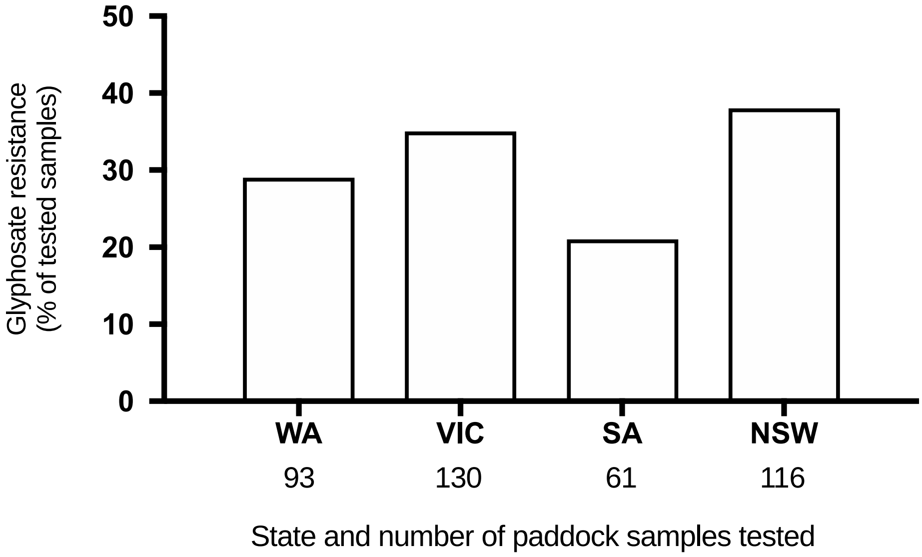

Figure 3: Resistance to 1.5L/ha Glyphosate 540 confirmed in farmer ryegrass samples during 2017 by Plant Science Consulting.

Differences between glyphosate products

Significant differences between glyphosate products have been identified in outdoor pot trials conducted in winter and summer annual weed species. Three undisclosed registered glyphosate products were compared in initial trials, with significant differences in weed control. Herbicide products Gly 1 and Gly 3 gave consistently greater control than Gly 2 on susceptible and resistant ryegrass (Figure 1). Surfactant differences between glyphosate products is likely to be a major factor determining final control. In the field, using glyphosate products with quality surfactants could be the difference between controlling ryegrass individuals with lower levels of resistance or allowing them to survive, cross-pollinate and increase the levels of glyphosate resistance.

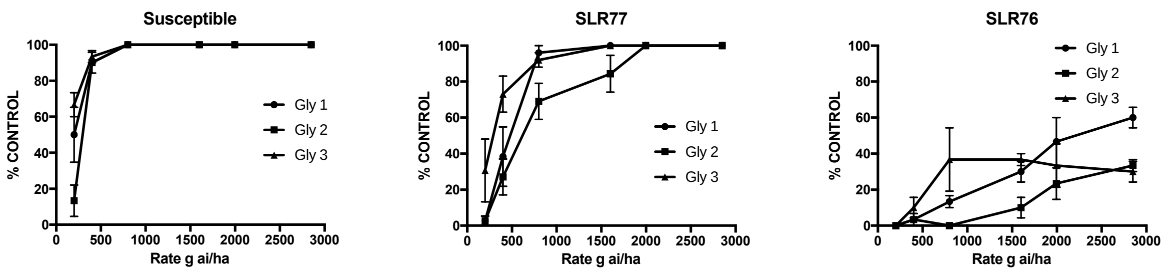

Figure 4: Efficacy of three glyphosate products on susceptible and glyphosate resistant ryegrass populations, SLR77 with weak glyphosate resistance and SLR76 with strong glyphosate resistance.

Differences in the level of control between glyphosate products in glyphosate-resistant sowthistle from NSW has also been confirmed (Figure 5). This information highlights that significant differences in control between glyphosate formulations occur, not only on glyphosate sensitive, but also on glyphosate resistant individuals.

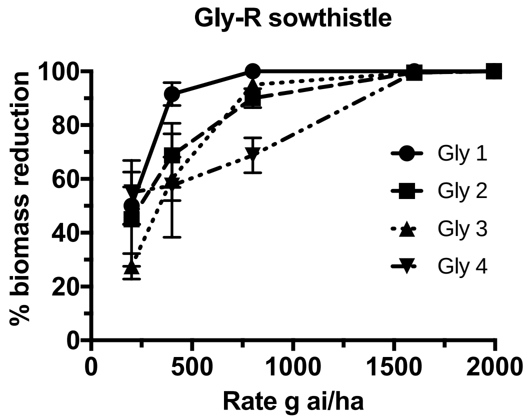

Figure 5: Efficacy of four glyphosate products on control of glyphosate resistant sowthistle as confirmed by outdoor pot trials by Plant Science Consulting.

Growth stage and glyphosate rate

Plant growth stage can play an important role in weed control. Even in resistant populations, improved control can be achieved at younger growth stages. Younger plants tend to have thinner cuticles than older plants therefore herbicide movement into younger plants is generally quicker. The effect of growth stage and glyphosate rate was investigated in a field trial in NSW on a susceptible and two glyphosate resistant sowthistle populations by Tony Cook, DPI Tamworth (Table 5). Increased control of glyphosate resistant sowthistle was observed at younger growth stages.

Table 5: First cases of confirmed glyphosate resistant sowthistle from Liverpool plains. Data presented as percent biomass reduction at three growth stages. Fallow spray timings from early to late summer. Data courtesy of Tony Cooke, DPI, Tamworth.

Glyphosate rate (g ai/ha)	**Growth Stage:** Early rosette 10cm	**Growth Stage:** Early bolting	**Growth Stage:** Mid-flowering
		Susceptible sowthistle- (% biomass reduction)	
360	79	76	0
720	100	81	33
1260	100	100	100
1800	100	100	100
		Resistant sowthistle biotype "Yellow" - (% biomass reduction)	
360	55	27	0
720	97	0	0
1260	95	16	0

1800	97	63	4

	Resistant sowthistle biotype "CRK" - (% biomass reduction)		
360	64	7	0
720	80	35	5
1260	91	71	58
1800	97	78	100

Weed Seed Sterilisation

Crop-topping is a procedure aimed at controlling weed seed set at pre-harvest timings with non-selective herbicides. One of the most commonly used practices is applying glyphosate pre-harvest to prevent seed set by flowering ryegrass. Only two glyphosate products (Nufarm Weedmaster DST® and Roundup Ultramax®) are registered for this practice in wheat, feed barley, canola and some pulse crops. A field trial was conducted in 2016 to investigate the effect of crop-topping a glyphosate resistant ryegrass population with 2.8 and 4.1L/ha of Weedmaster DST at two timings (flowering and milky dough). Additionally, laboratory testing confirmed that this population was not target site resistant, therefore resistance most likely is via the reduced translocation mechanism. This is the most common glyphosate resistance mechanism identified in ryegrass. Viability testing of the seed after maturation revealed that the reduction in seed germination was between 9-22% indicating that at least 80% of the seed remained viable. Glyphosate was therefore not effective in sterilising glyphosate resistant ryegrass. In addition, glyphosate resistance can increase if susceptible ryegrass is sterilised leaving only resistant individuals to cross-pollinate with each other.

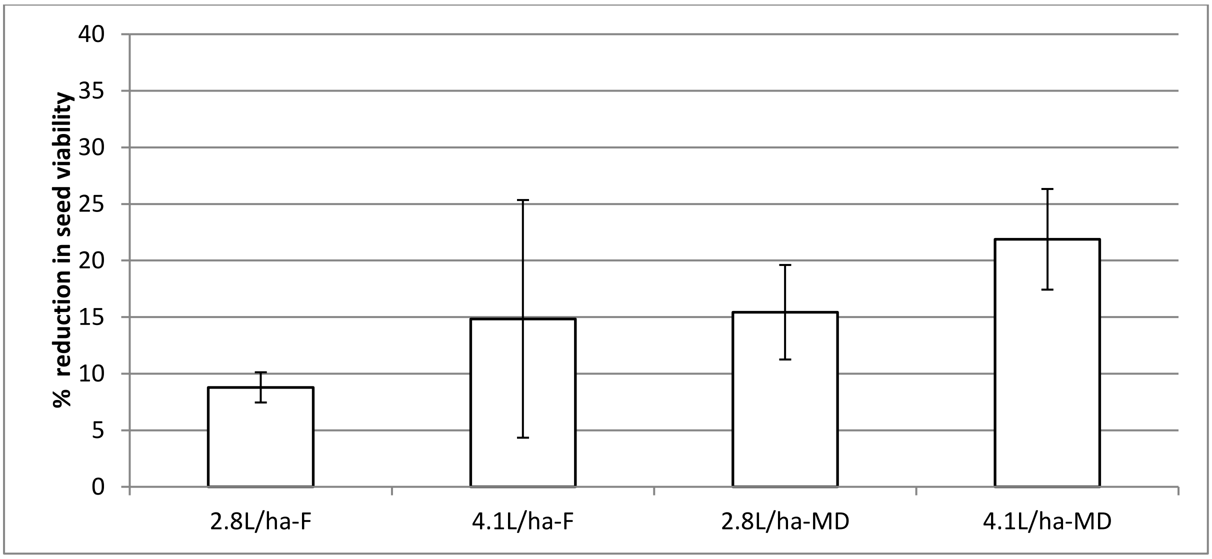

Figure 6: Reduction in viability of ryegrass seed after crop-topping with Weedmaster DST at two timings, F - flowering and MD = milky dough. Trial conducted at Roseworthy SA in 2016.

Effect of temperature

Temperature has been identified as playing a major role in glyphosate efficacy. Significant differences were identified in wild oat control with the same glyphosate product in plants sprayed in outdoor summer or winter pot trials in South Australia (Figure 7). Complete control of a wild oat population was not achieved in summer even at higher than label rates (1600g ai/ha glyphosate) whereas in winter trials 400g ai/ha glyphosate resulted in complete control. These large differences suggest that controlling wild oats in summer fallows can be affected by high temperatures.

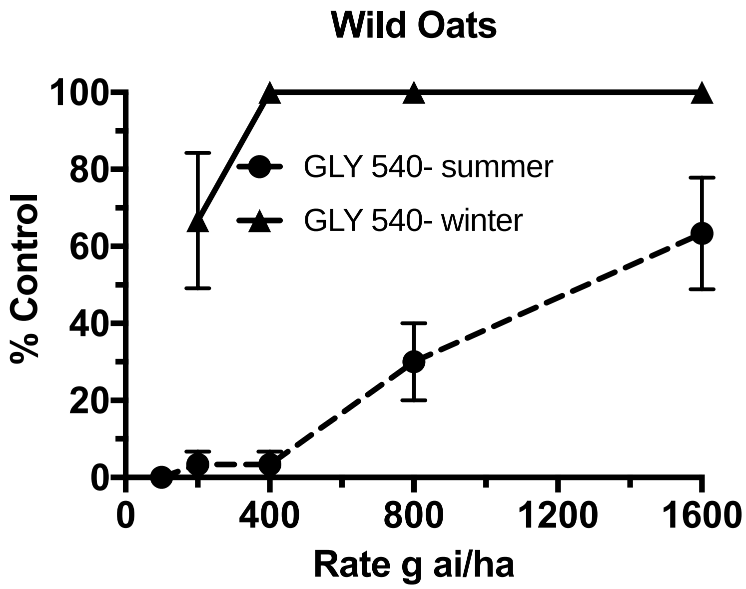

Figure 7: Control of wild oats with the same glyphosate product in outdoor summer and winter pot trials.

A current study is investigating the effect of temperature on control of glyphosate resistant sowthistle from NSW. Initial trials have confirmed greater control with glyphosate at lower temperatures, particularly of resistant biotypes (Table 5). These findings suggest that applying glyphosate at lower temperatures can improve control of glyphosate resistant sowthistle. At lower temperatures, glyphosate remains in liquid form on plant surfaces longer leading to greater uptake, particularly at higher humidity. Maximising glyphosate uptake is therefore likely to improve weed control and factors such as lower temperature and higher humidity influence uptake.

Table 5: Effect of temperature in control of four biotypes of sowthistle with Glyphosate 540. Data is LD50= dose required to kill 50% of the population.

Biotypes	**Resistance level**	**LD50 (g a.i/ha)**	
		20^{oC}	**30^{oC}**
Yellow	strong	439	962
Crocket	strong	389	919
White	weak	132	389
GI	susceptible	135	152

Conclusion

Incorporating herbicides with multiple MOA as part of an integrated weed management strategy can help in combatting multiple resistant ryegrass and reduce selection pressure. Where confirmed with resistance testing, post-emergent selective herbicides can be used effectively. Understanding how herbicides such as clethodim and glyphosate behave under different conditions can improve weed control. Greater control of susceptible and some glyphosate resistant individuals is possible by treating younger plants under cooler temperatures with quality glyphosate products.

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