New pre–seeding grass selective herbicides—How well do they work in zero or no-tillage systems?

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KEY MESSAGES

- Sowing with knife points resulted in greater crop establishment, compared with discs, but did not affect crop yield.
- Sowing method (knife points or discs) did not affect performance of pre-seeding herbicides.
- Under both sowing methods, Product X provided more effective initial annual ryegrass control than Triflur Xcel®, but final reduction in annual ryegrass seed heads and biomass were equivalent between Triflur Xcel® at 2.5 L/ha, Boxer Gold® at 2.5 L/ha and Product X.
- Low or high rates of stubble biomass (in a knife point system) did not affect crop growth or yield.
- Where stubble biomass was low, Triflur Xcel®, Boxer Gold® and Product X were equally effective.
- Where stubble biomass was high, Triflur Xcel® and Boxer Gold® are less effective when water spray volume is low. Efficacy of Product X was not affected by water rates.

AIMS

Zero tillage systems (discs) have many benefits, but unfortunately they reduce the effectiveness of pre-seeding, grass selective herbicides, like trifluralin. This is due to reduced soil incorporation of the herbicide, compared to no tillage seeding systems (knife points), and high stubble burdens that bind the herbicide (Chauhan et al. 2006). The overuse of trifluralin in no tillage seeding systems has resulted in a dramatic increase in the development of trifluralin resistance (D'Emden and Llewellyn 2006; Owen et al. 2007). Both of these factors have led to the need to find alternative pre-emergent herbicides to control annual ryegrass in zero and no-tillage seeding systems.

There are new pre-seeding grass selective herbicides, which are more soluble and less volatile than trifluralin. These herbicides include Boxer Gold® (prosulfocarb and s-metolachlor), the Syngenta product released in 2008, and Product X, a product that has not yet been released. The higher solubility and lower volatility of these products may allow them to act more effectively in zero tillage systems, compared to trifluralin.

The aims of this research were to determine the effect of sowing method and the effect of stubble and water spray volume on performance of pre-seeding grass selective herbicides.

METHOD

WANTFA

Prior to sowing the site was treated with Spray.Seed® at 2 L/ha and annual ryegrass (cv Safeguard®) was broadcast at 15 kg/ha. The trial was arranged in a split-plot design. The main-plot treatment was sowing with knife points or discs and the sub-plot treatments were pre-seeding herbicides (Table 1). Herbicides were applied on 15 May 2008, directly before sowing 100 kg/ha of Wyalkatchem wheat with 150 kg/ha Agras fertiliser, using knife points or discs (with press wheels). The entire trial was treated with 25 g/ha Monza® on 6 June to control barley grass, and with 50 kg/ha of urea on 18 June.

Measurements included emergence of annual ryegrass and wheat (10 June and 15 July), seed head production (2 October) and biomass (5 November). The crop was harvested on 10 December and measurements were taken on crop yield, protein, screenings and 500 seed weight.

Wongan Hills

The trial was arranged in a split-plot design. The main-plot treatment was stubble or no stubble, which was established by spreading canola stubble in the stubble plots on 8 April 2008. Spray.Seed® at 2 L/ha was sprayed on 19 June. The sub-plot treatments were pre-seeding herbicides at varying water spray volumes (Table 2). The herbicide treatments were sprayed on 20 June, directly before sowing 70 kg/ha of Wyalkatchem wheat with 80 kg/ha MacroPro Plus fertiliser (with knife points). On 17 July, 55 L/ha Flexi-N was applied and on 25 July, broadleaf weeds were controlled with 150 mL/ha Lontrel and 1 L/ha Jaguar. No grass selective herbicides were applied to the trial, apart from the pre-seeding herbicide treatments.

Measurements included emergence of annual ryegrass and wheat (16 July and 1 August), seed head production (10 October) and biomass (4 November). The crop was harvested on 27 November and measurements were taken on crop yield, protein, screenings and 500 seed weight.

RESULTS

WANTFA

Wheat

Initial emergence from the plots sown with discs was very low, compared to emergence from plots sown with knife points. While emergence from disc plots gradually increased over the subsequent weeks, it did not catch up to knife point plots. Crop counts (approximately four weeks after sowing) found 156 plants/m^2 in the disc plots, which was significantly lower than the 199 plants/m^2 in the knife point plots (P: 0.012, l.s.d.: 24.88). Likewise, wheat seed heads was significantly greater in the plots sown with knife points compared with disc plots (392 and 336 heads/m^2, P: 0.039, l.s.d.: 50.44). However, crop biomass and yield were not influenced by sowing method. The herbicide treatments had no effect on wheat emergence, growth, yield or grain quality.

Annual ryegrass

The initial number of annual ryegrass (10 June, four weeks after sowing) was uniform between treatments. However, by 15 July (eight weeks after sowing), Product X was providing more effective weed control than Triflur Xcel® (Table 1). Triflur Xcel® at 2.5 L/ha, Boxer Gold® at either rate or Product X all reduced seed heads to a greater extent than Triflur Xcel® at 1.5 L/ha (and the control, Table 1). Likewise, annual ryegrass biomass was significantly lower than the control for Triflur Xcel® at 2.5 L/ha, Boxer Gold® at 2.5 L/ha and Product X.

Sowing methods had no effect on annual ryegrass emergence or control. On 10 June, average annual ryegrass density was 9 plants/m^2 in the disc plots and 11 plants/m^2 in the knife point plots. On 15 July, average annual ryegrass density increased to 43 plants/m^2 in the disc plots and 52 plants/m^2 in the knife point plots. Likewise, sowing method had no impact on annual ryegrass seed head production or biomass.

Table 1 **Average number of annual ryegrass plants/m^2 (on 15 July), average seed heads/m^2, average dry biomass (g/m^2) and crop yield (t/ha), significant at $P < 0.001$**

Treatment	Initial annual ryegrass emergence (plants/m^2)	Annual ryegrass seed (heads/m^2)	Annual ryegrass biomass (g/m^2)
Control (no herbicide)	97	72	34.5
Triflur Xcel® at 1.5 L/ha	52	44	28.7
Triflur Xcel® at 2.5 L/ha	52	22	17.8
Boxer Gold® at 1.5 L/ha	39	26	24.2
Boxer Gold® at 2.5 L/ha	40	29	12.9
Product X	28	20	6.3
l.s.d.	19.09	21.13	13.31

Wongan Hills

Wheat

Average crop emergence was 159 plants/m^2, seed head production was 227 heads/m^2, dry biomass was 534.3 g/m^2 and yield was 2.3 t/ha. Wheat emergence, growth, yield or grain quality was not affected by any of the treatments.

Annual ryegrass

There was significantly fewer annual ryegrass plants in the stubble free plots compared to the stubble plots (7 and 44 annual ryegrass/m^2, P: 0.032, l.s.d.: 30.82). This is likely due to increased emergence in the stubble plots, due to surface soil moisture retention, and the reduced efficacy of knockdown herbicides where stubble density is high. Annual ryegrass seed head production was also greater in the stubble plots (9 and 45 seed heads/m^2, P: 0.033, l.s.d.: 30.03), although annual ryegrass biomass was not influenced by stubble rate.

In the stubble plots, both Triflur Xcel® and Boxer Gold® gave significantly better weed control at water application rates of 100 or 150, compared to 50 L/ha (Table 2). Product X was not influenced by water volume. In the stubble free plots, all herbicides were equally effective (data not presented). There was a greater number of annual ryegrass seed heads in the plots treated with Triflur Xcel® at 50 L/ha, compared to 150 L/ha. Seed head production was similar for Boxer Gold® and Product X at all water volumes. Likewise, annual ryegrass biomass was reduced by Triflur Xcel® at water application rates of 100 or 150, compared to 50 L/ha, but biomass of annual ryegrass treated with Boxer Gold® and Product X were uniform across water spray volumes.

Table 2 **Average annual ryegrass plants/m^2, average seed heads/m^2 and biomass (g/m^2), significant at $P < 0.001$**

Treatment	Initial annual ryegrass emergence (plants/m^2)	Annual ryegrass seed (heads/m^2)	Annual ryegrass biomass (g/m^2)
Control (no herbicide)	48	67	14.3
Triflur Xcel® 50 L/ha	35	40	7.9
Triflur Xcel® 100 L/ha	17	23	2.8
Triflur Xcel® 150 L/ha	12	11	2.1
Boxer Gold® 50 L/ha	37	32	5.3
Boxer Gold® 100 L/ha	18	23	5.0
Boxer Gold® 150 L/ha	16	19	3.8
Product X 50 L/ha	29	16	3.3
Product X 100 L/ha	21	12	3.9
Product X 150 L/ha	25	24	4.2
l.s.d.	15.83	21.36	5.037

CONCLUSION

WANTFA

Crop establishment was more successful following sowing by knife points rather than discs, but this did not impact final yield. Sowing method (knife points or discs) did not affect herbicide performance. Triflur Xcel® at 2.5 L/ha, Boxer Gold® at 2.5 L/ha and Product X in either system reduced annual ryegrass seed head production and biomass equally effectively, although Product X provided most effective initial weed control.

Wongan Hills

Stubble increased initial weed emergence, but had no impact on crop growth or yield. Where stubble biomass was low, all herbicides at all water rates were equally effective. Where stubble biomass was high, Triflur Xcel® and Boxer Gold® provided less effective weed control at low water rates, but performance of Product X was not affected by water rates. Product X usually provides greater control than was observed in this trial, possibly due to low soil moisture levels at sowing.

KEY WORDS

Triflur Xcel®, Boxer Gold®, Product X, minimum tillage

ACKNOWLEDGMENTS

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Velocity®—An alternate mode of action for the control of wild radish in cereals

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KEY MESSAGES

Bayer Cropscience has developed Velocity (37.5 g/L pyrasulfotole + 210 g/L bromoxynil + 9.38 g/L mefenpyr-diethyl) for the control of wild radish (*Raphanus raphanistrum*) and other annual broadleaf weeds in cereals. Pyrasulfotole, branded as photo-X® technology acts on the HPPD enzyme which, like the PDS enzyme, is also involved in carotenoid biosynthesis. Velocity controls PDS resistant as well as susceptible wild radish populations. Field studies confirm the ability of Velocity to be a useful tool for growers managing wild radish.

AIMS

- To evaluate Velocity on a wild radish population resistant to PDS (phytoene desaturase) inhibiting herbicides.
- To evaluate herbicide coverage on the efficacy of Velocity against wild radish.
- To evaluate the field activity of Velocity for the control of wild radish.

METHOD

Velocity dose response pot study

A dose response study evaluated the effect of increasing application rates of Velocity on seedling survival and biomass production of two wild radish populations (WARR 5 and WARR 25).

Seeds of the two wild radish populations (WARR 5 and WARR 25) were planted at 2 cm depth into 17 cm diameter pots filled with potting mix (25% river sand, 25% peat moss and 50% mulched pine bark v/v) at a density of 12 seeds per pot. After planting the pots were watered and then moved to an outside growth area where they were watered and fertilised as necessary.

Herbicide treatments (Table 1) were applied at the two true-leaf stage of wild radish plants. Treatments were applied using a track-mounted cabinet sprayer, fitted with two flat-fan jets (Teejet XR11001) at a 50 cm spray height, delivering a water volume of 110 L/ha at 3.6 kph and 210 KPa pressure.

Table 1 **Herbicides and application rates used in the Velocity dose response pot study**

Herbicide treatments	Application rates (g pyrasulfotole/ha)	Product rates (L/ha)
Velocity*	0, 9.375, 18.75, 25.1, 37.5, 75 and 150	0, 0.25, 0.5^R, 067^R, 1.0 and 2.0
Brodal Options®		200 mL/ha
Glean®		25 g/ha + BS1000 at 0.1% v/v
2,4–D amine		1.0

* Hasten at 1% v/v was added to all Velocity treatments.

^{R} Proposed registered rate.

Plant survival and biomass production were assessed 21 days after herbicide treatment application. At this time surviving wild radish were counted, harvested by cutting at ground level before oven drying at 70°C for 48 hours and weighing.

Velocity growth stage and coverage pot study

Fifty wild radish seeds per pot were planted on 19/9/2008. Pots were routinely watered. Pots were fertilised as required using Yates Thrive all purpose fertiliser. Treatments were applied using a track-mounted cabinet sprayer, fitted Hardi 4110–08 nozzles delivering a water volume of 100 L/ha at 3 kph and 200 KPa pressure.

Table 2 shows the herbicide application dates and growth stages of wild radish at each application time being primarily 2, 4 and 6 leaf respectively. At each application time, half the pots were thinned so there was nil or little plant to plant leaf overlap. The leaf to leaf overlap in the non thinned pots was 2–3 per cent, 60–70 per cent and 80–90 per cent respectively for application timings one to three. Herbicide treatments were evaluated based on a visual rating of weed whole tops, fresh weight and weed survival counts. Fresh weight data is presented. The 2 leaf application harvest was conducted four weeks after application. The remaining harvests were conducted six weeks after application.

Table 2 **Application timing, growth stage and overlap percentage for the Velocity growth stage and coverage pot study**

Application timing	Date	Growth stage	Growth stage range	Overlap
1	3 October	2 leaf (lf)	2lf (80%):3lf (20%)	2 to 3%
2	14 October	4 leaf	3lf (2%):4lf (95%):5lf (3%)	60 to 70%
3	21 October	6 leaf	5lf (10%):6lf (90%)	80 to 90%

Field evaluation

Velocity was evaluated for its efficacy on wild radish following post emergence application in winter cereals in field trials across Australia during the 2004 to 2008 seasons. 21 of those trials had direct comparison to Tigrex®. At each site the trial design was a randomised block design with three or four replicates of herbicide treatments (Table 4) applied on plots measuring 10 m x 2 m in size to 15 m x 2.5 m. Wild radish density ranged from 0.3 to 243 plants/m^2 with mean density of 67 plants/m^2.

Herbicide treatments were evaluated for final control based on a visual rating of weed whole tops control and weed survival counts. Visual control data is presented to reflect observed weed biomass control.

RESULTS

Velocity dose response pot study

The pyrasulfotole containing herbicide Velocity effectively controlled two wild radish populations with high survival to the PDS inhibitor Brodal Options at 200 mL/ha. At the low rate (0.25 L/ha) of Velocity, i.e. below recommended rate, 2–3 per cent of both populations survived. There was no wild radish survival at the 0.5 L/ha rate and above of Velocity. Velocity was more effective in controlling wild radish populations than the industry standards of Brodal Options (200 mL/ha) and 2,4–D amine (1.0 L/ha). Velocity was more effective in controlling the resistant wild radish population than the industry standard Glean (25 g/ha).

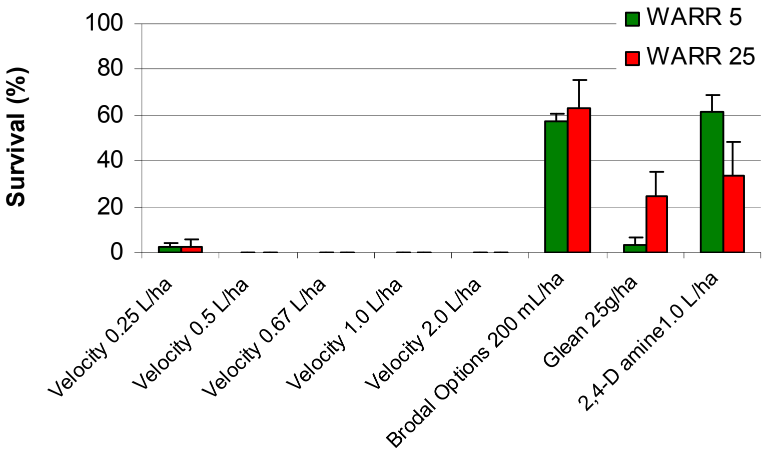

Figure 1 Effect of increasing application rates of Velocity and single application rates of chlorsulfuron (Glean), diflufenican (Brodal Options) and 2,4–D amine on the survival of wild radish populations (WARR 5, WARR 25). Bars represent standard errors of the mean of four replicates.

Low biomass levels were recorded for nearly all treatments where substantial levels of survival occurred indicating that surviving plants were severely affected by herbicide treatments. Herbicide affected plants although unlikely to be competitive within a crop would potentially survive to complete seed production. Only the diflufenican resistant WARR 5 population produced higher levels of biomass in combination with higher levels of population survival.

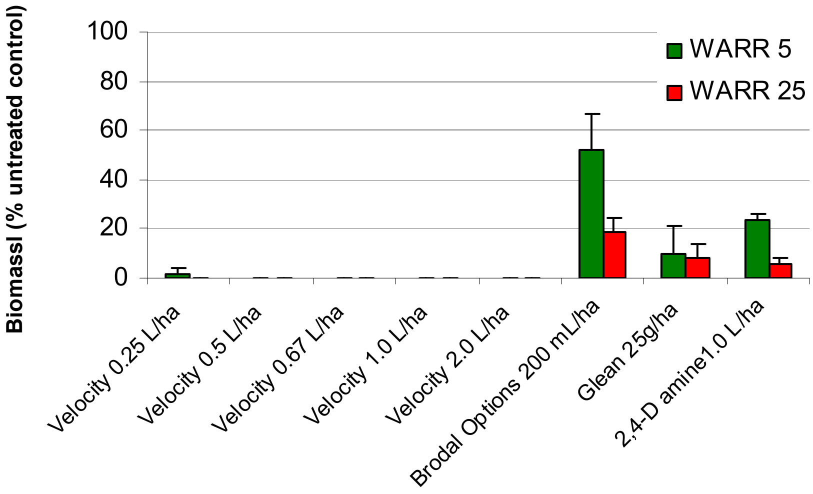

Figure 2 Effect of increasing application rates of Velocity and single application rates of chlorsulfuron (Glean), diflufenican (Brodal Options) and 2,4–D amine on the biomass as a percentage of the untreated control of diflufenican resistant (WARR 5) and susceptible (WARR 25) wild radish populations. Bars represent standard errors of the mean of four replicates.

Velocity growth stage and coverage pot study

Velocity at 0.5 L/ha provided complete control of 2 leaf wild radish (Table 3). There was no influence of removing leaf overlap as minimal leaf overlap was present in the overlap pots. Delayed application to 4 leaf resulted in unacceptable control at 86.3 per cent. The removal of weed leaf overlap negated the effect of delayed application. Further delaying application to mainly 6 leaf, further reduced wild radish control to 52.5 per cent. The removal of weed leaf overlap partly negated the effect of delayed 6 leaf application with Velocity at 0.5 L/ha plus Hasten at 1 per cent v/v providing suppression at 86.5 per cent (Table 3). Field studies indicate the need for a higher Velocity rate of 0.67 L/ha on 6 leaf wild radish (Table 4).

Table 3 **Control of 2, 4 or 6 leaf wild radish fresh weight by Velocity at 0.5 L/ha plus Hasten at 1% v/v with or without leaf overlap**

Time	Growth stage	Coverage	Overlap	Mean fresh weight (g/pot)		Mean control (%)
				Untreated	Velocity 0.5 L/ha	
1	2 leaf	Overlap	2–3%	222.3	0	100
1		No overlap		171	0	100
2	4 leaf	Overlap	60–70%	776	106	86.3
2		No overlap		606.3	15.3	97.5
3	6 leaf	Overlap	80–90%	767	364.3	52.5
3		No overlap		666.7	89.7	86.5
		l.s.d. (P = 0.05)			101.1	

Field evaluations

Velocity at 0.5 L/ha provides reliable control of up to 4 leaf susceptible wild radish when used as directed (Table 4). At later wild radish growth stages, up to 6 leaf a higher rate of Velocity (0.67 L/ha) is required for good control. Velocity can provide acceptable levels of control of larger wild radish but results are more variable due to the requirement for good herbicide coverage on each weed present in the population. Velocity is used with Hasten® at 1 per cent v/v.

Table 4 **Observed control of wild radish within field cereal crops by Velocity plus Hasten at 1% v/v where Tigrex was in the same trial conducted in 2004 to 2008**

Wild radish maximum stage		Velocity (L/ha)		Tigrex (L/ha)	Trials
		0.5	0.67	0.5	
4 leaf	Mean	97.6	99	99	5
	Std error	1.5	0.9	0.7	
6 leaf	Mean	89.4	93.6	78.1	9
	Std error	2.4	2.5	4.7	
8 leaf	Mean	88	94	92	7
	Std error	4.6	2.8	3.5	

CONCLUSION

Field and pot studies confirmed the ability of Velocity to be a useful tool for growers in managing resistant and susceptible wild radish populations within the winter cereal cropping systems. Dose response studies indicated the enhanced efficacy of Velocity, over the industry standard herbicide treatments in controlling the Group F resistant wild radish populations. Extensive field evaluations confirmed the efficacy of Velocity in controlling wild radish at up to the 6–leaf stage within winter cereal cropping systems. Pot studies demonstrated the need to apply Velocity onto young wild radish for good coverage of each individual wild radish plant to ensure good control.

Pyrasulfotole in Velocity is a Group H mode of action. Unlike diflufenican and picolinafen which target the PDS enzyme (Group F), pyrasulfotole targets the HPPD enzyme (4-hydroxphenylpyruvatedeoxygenase). In conjunction with its other active constituent, the Group C bromoxynil, Velocity acts on the HPPD enzyme and the Qb binding site, a different pathway process to that of the PDS enzyme.

Therefore, Velocity controls wild radish populations that are resistant to PDS inhibiting herbicides (Group F).

KEY WORDS

wild radish, control, velocity

ACKNOWLEDGMENTS

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An application for registration of Velocity has been made. At the time of Crop Updates publication, this product is not registered.

Paper reviewed by: John Ashby, BayerCropScience Pty Ltd, 391–393 Tooronga Rd, East Hawthorne, Victoria 3123

Herbicide tolerance of new barley varieties

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KEY MESSAGES

- The new barley varieties Buloke and Hindmarsh were tested for the first time in a WA Herbicide tolerance trial.
- The new barley varieties showed good tolerance to all the pre-emergent herbicides/mixtures. The mixture of metribuzin with Boxer® Gold was as safe as its mixture with trifluralin.
- Hindmarsh and Roe tolerated all the herbicides/mixtures well.
- Baudin showed sensitivity to Tigrex® 1 L/ha and Buloke to Axial® 0.3 L and Diuron 0.4 L + MCPA amine 0.5 L/ha.
- Hannan showed sensitivity to a higher number of herbicides (23% of the treatments tested) than the other varieties.

AIM

To evaluate the herbicide tolerance of recently released barley varieties.

METHOD

A field trial was laid out in criss-cross design under weed free conditions at GSARI Katanning in which six barley varieties (Baudin, Buloke, Hannan, Hindmarsh, Lockyer and Roe) were sown on 17 June 2008 on a loamy sand/sandy duplex soil ($CaCl_2$ measured pH 4.5 and OC 1.54%) with three replications. The varieties were sown 2–3 cm deep in 10 m wide parallel randomised strips at a sowing rate of 75 kg/ha using Bourgault 8810 floating hitch cultivator with knife points and press wheels. Agstar Extra Plus at 100 kg/ha was applied with the seed.

A range of herbicide treatments (Table 1) were applied randomly in three meter wide strips across all the variety strips before crop seeding (17 June), at 4–5 leaf stage (18, 19 and 21 August) and 5–6 leaf stage (22 August). Every 11th plot was kept as an untreated control to assess the spatial variability. At the time of pre-emergent herbicide treatment application (17 June), gravimetric soil moisture content at 0–10 depth was 11 per cent and within 2 weeks of these treatments being applied, 17.6 mm more rain fell. To determine the effect of pre-emergent herbicide treatments (selected only) on plant establishment, the barley plant numbers were counted from two randomly placed 50 cm x 50 cm quadrats per plot (14 August). The barley varieties were also assessed for visual injury in terms of leaf spotting, yellowing, height and biomass reduction at 2–4 weeks after each treatment application and again at the heading stage using a 0 to 100 per cent scale, where 0 = no visible injury and 100 = complete plant death (24 July, 9 September and 15 October). The trial was harvested on 24 December 2008 and net plot size was 10 m X 1.8 m. The grain yield data was subjected to Reml analysis (spatial) using the Genstat programme.

Total rainfall from June to December at Katanning was 304 mm. June and July were wetter, August and first three weeks of September were dry, and again October, November and December received some rain (21–50 mm) and gave a soft/wet finish to the season. No frost effects were observed in this trial.

RESULTS AND DISCUSSION

The effect of herbicides on barley varieties' growth, development and grain yield (Table 1) was as follows:

- The herbicides applied before seeding did not have any significant negative effect on plant establishment, crop growth and development, and ultimately on grain yield of the varieties. Application of metribuzin 112.5 g a.i./ha (e.g. Lexone®) in mixture with Boxer Gold 2.5 L/ha on all the varieties was as safe as in mixture with trifluralin 1440 g a.i./ha (e.g. Triflur® X).

- Jaguar® and Tigrex® at 1 L/ha, and Paragon® at 0.5 L/ha caused an estimated 10 per cent leaf spotting across all the varieties, but these symptoms were out grown by the time crop reached the flowering stage. Tigrex® reduced grain yield of Baudin (a standard variety) and Hannan significantly and these results are contrary to the previous results (Dhammu et al. 2007 and http://www.nvtonline.com.au/herbicide-tolerance.htm).
- Affinity® 50 g + MCPA amine 0.5 L/ha caused variable leaf spotting (3–10%) on the varieties with Hindmarsh being the least affected variety. There was no significant effect on grain yield and the results are consistent with the previous results. Affinity® is also available in the liquid formulation as Affinity® Force in the market and 50 g of Affinity® is equal to 85 mL of Affinity® Force.
- Cheetah® Gold 1 L, Achieve® 380 g, Eclipse® 5 g + MCPA LVE 0.5 L, Precept® 2 L and MCPA anime 2 L/ha caused significant yield reduction in Hannan without any visual negative effects on crop growth and development. In previous trials conducted at Katanning during 2006 and 2007, Hannan tolerated these herbicides quite well.
- Axial® 0.3 L and Diuron 0.4 L + MCPA 0.5 L/ha reduced grain yield of Buloke significantly, where as Achieve® 380 g and Eclipse® 5 g + MCPA LVE 0.5 L/ha caused significant loss in grain yield of Lockyer. Lockyer results are also contrary to the previous two years' results.
- Hindmarsh and Roe tolerated all the applied herbicides quite well and Roe results are consistent with the previous results.
- As recently released varieties Buloke and Hindmarsh were included for the first time in WA herbicide tolerance trials in 2008, these need further testing to confirm the results found in this trial.

Note: During 2006, Hannan was tested as WABAR2321, Lockyer as WABAR2288 and Roe as WABAR2310.

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KEY WORDS

barley, herbicide, tolerance, grain yield

ACKNOWLEDGMENTS

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Table 1 **Effect of herbicides on grain yield (% of untreated control) of barley varieties at Katanning (08GS23)**

No.	Herbicides (rate/ha)	Timing	Baudin	Buloke	Hannan	Hindmarsh	Lockyer	Roe
	Untreated control	**Grain yield (kg/ha)**	**100 (2284)**	**100 (2571)**	**100 (2947)**	**100 (2498)**	**100 (2894)**	**100 (2416)**
1	Stomp® 330 1.8 L	Before	106	105	109	98	112	100
2	Triflur® X 3 L	seeding	118	95	99	102	116	125
3	Triflur® X 1 L + Lexone® 150 g	"	109	110	102	97	99	105
4	Dual® Gold 0.5 L	"	106	105	94	104	106	110
5	Diuron 1 L + Dual® Gold 0.5 L	"	110	112	105	97	105	112
6	Boxer® Gold 2.5 L	"	113	116	100	87	107	96
7	Boxer® Gold 2.5 L + Lexone® 150 g	"	115	117	100	100	110	131
8	Glean® 20 g	Z14–Z15	106	95	100	97	88	103
9	Jaguar® 1 L	"	107	101	91	100	109	111
10	Cheetah® Gold 1 L	"	91	114	**81**	95	96	96
11	Axial® 0.3 L	"	98	**83**	93	109	104	103
12	Hoegrass® (375) 200 mL + Achieve® 200 g	"	97	103	112	105	95	112
13	Achieve® WG 380 g	Z14–Z15	98	90	**86**	111	**79**	97
14	Ally® 7 g	"	109	116	96	116	107	110
15	Tigrex® 1 L	"	**84**	95	**86**	93	94	99
16	Buctril® MA 1.4 L	"	107	100	99	106	100	110
17	Affinity® 50 g + MCPA 0.5 L	"	106	91	89	105	98	101
18	Eclipse® 5 g + MCPA LVE 0.5 L	"	96	102	**83**	106	**84**	95
19	Hoegrass® 375 1.5 L	Z14–Z15	101	93	94	93	97	104
20	Diuron 0.4 L + MCPA (Amine) 0.5 L	"	97	**83**	94	115	110	108
21	Precept® 2 L	Z15	88	98	**85**	107	94	93
22	Paragon® 0.5 L	"	103	98	108	90	88	107
23	MCPA amine 50% 2 L	"	102	90	**86**	90	97	102
24	2,4–D amine 625 1.3 L	"	101	101	106	97	95	123
25	2,4–D LV ester 680 0.8 L	"	103	104	112	101	114	121
26	Kamba® 500 0.4 L	"	100	93	92	99	88	95
l.s.d. (0.05) Herbicides v/s control			14	17	12	14	15	16
l.s.d. (0.05) Herbicides v/s Herbicides			18	21	15	18	19	20
CV (%)			13	16	11	13	14	14

Treatments 8–12 were nominated to apply at Z12–Z13 and Treatments 13–18 at Z13–Z14. Due to frequent rains in July (96 mm and 25 rainy days), the trial site was almost waterlogged. The treatments were applied in August when the site became accessible.

Treatment 8 applied with BS® 1000 0.1%, 10 and 21 + Hasten® 1%, 11+ Adigor® 0.5%, 12 and 13 + Supercharge® 0.75%, 14 and 19 + BS® 1000 0.25%, and 18 + Uptake® oil 0.5% (v/v).

Figures in **bold** are significantly lower yielding than the untreated control.

Herbicide tolerance of Desi chickpea—influence of seeding depth and rainfall

Harmohinder Dhammu[1], Research Officer and **David Nicholson**, Technical Officer, Department of Agriculture and Food, Western Australia
[1]Northam and [2]Geraldton

KEY MESSAGES

- Desi chickpea varieties tested in the trial were Genesis 510, Genesis 836 and Sonali.
- Shallow seeding followed by heavy frequent rainfalls during early crop growth stages could lead to crop damage from soil active and residual herbicides like simazine and metribuzin.
- Diuron 1 kg a.i./ha applied before seeding the crop was safer on all the chickpea varieties than simazine 1 kg a.i./ha applied at the same time.

AIM

To evaluate the herbicide tolerance of new Desi chickpea varieties.

METHOD

A field trial was laid out in a criss-cross design under weed free conditions at Mingenew on Chris Gillam's property. Three Desi chickpea varieties (Genesis 510, Genesis 836 and Sonali) were sown on 4 June 2008 on a clay soil ($CaCl_2$ measured pH 5.4 and OC 0.5%) with three replications. The seed was treated with P—Pickle T® (200 mL/100 kg) and Alosca® Group N granular inoculum (10 kg/ha) before sowing. The varieties were sown 3 cm deep in 10 m wide parallel randomised strips at 100 kg/ha seed rate using knife points, press wheels and rollers. The varieties were sown shallower than the normal seeding depth of 5–8 cm as ground was very hard due to dry conditions. DAP at 80 kg/ha was applied with the seed.

A range of herbicide treatments (Table 1) were applied randomly in three meter wide strips across all the variety strips before crop seeding (4 June), immediately post plant/PSPE (6 June) and at 4–6 node stage (1 July). Every 8th plot was kept as an untreated control to assess the spatial variability. At the time of pre-emergent herbicide treatment application (4 June), gravimetric soil moisture content at 0–10 depth was 4.5 per cent which was quite low for activation of soil active and residual herbicides like simazine. However, within 2 weeks of these treatment applications, 35.4 mm of rain fell which might have activated the pre-emergent herbicides to their full potential. To determine the effect of herbicide treatments on plant establishment, the chickpea plant numbers across all the varieties were counted from two randomly selected 50 cm x 50 cm quadrats per plot on two occasions (30 June and 8 August). Plant height of a randomly selected 10 plants of Sonali (only) from each plot was also measured from ground level to base of the last fully opened leaf on the main stem (21 August). The chickpea varieties were also assessed for visual injury in terms of yellowing of leaves and biomass reduction at 2–4 weeks after each treatment application and again at the flowering stage using a 0 to 100 per cent scale, where 0 = no visible injury and 100 = complete plant death (30 June, 14 July, 4 August, 22 August, 2 and 8 September).

Chlorothalonil (720 g/L) as Bravo® 500 mL/ha was applied twice (6 and 29 August) as a preventative measure against Ascochyta blight. A blanket spray of clethodim (240 g/L) as Select® 500 mL/ha was applied to control a very low density of grass weeds (22 July). BETA-cyfluthrin (25g/L) as Bulldock® 600 mL/ha was sprayed to control budworm (3 September).

The trial was harvested on 17 November 2008 and net plot size was 9.24 m X 1.8 m. The plant counts (8 August data) and grain yield data was subjected to Reml analysis (spatial) using the Genstat programme.

Total rainfall from June to November at Mingenew was 317 mm. At the trial site, the distribution of rainfall from June to October was uneven. June, July and September received good rainfall, where as August and October were comparatively dry. July had 52 per cent (157 mm) of the total rainfall received from June to October, with 20 rainy days and also 6–7 days with heavy rainfall events, e.g. 29.2 mm rain fell in one day on 16 July.

RESULTS AND DISCUSSION

The effect of herbicides on Desi chickpea varieties (Table 1) was as follows:

- Three weeks after application of pre-emergent herbicide treatments (WAT), there was no significant negative effect of herbicides on chickpea plant establishment and seedling growth and development.
- Five WAT, all the treatments resulted in a slight to moderate yellowing of plants (10–30%) across all the varieties and flumetsulam 20 g/ha treated plants were the most yellowish in appearance. Isoxaflutole 75 g/ha applied immediately post plant (IPP) after basal simazine (before seeding) caused more yellowing than isoxaflutole 75 g/ha applied alone (IPP). All the treatments also caused 10–20 per cent stunting of the plants in all the varieties. Diuron 1 kg a.i./ha (applied before seeding) did not have any negative effect on any of the varieties.
- Nine to 10 WAT, all the plots that had Simazine 1 kg a.i./ha as a basal treatment, registered significantly less plant population and Sonali lower plant height as compared to the untreated control. Visually other varieties had a plant height trend very similar to Sonali. Metribuzin 285 g/ha had similar negative effects on these parameters. The surviving plants under these treatments showed less yellowing compared to that recorded at 5 WAT. Diuron 1 kg a.i./ha and isoxaflutole 75 g/ha (IPP) had a plant population across all the varieties and Sonali plant height on a par with the untreated control.
- Simazine 1 kg a.i./ha (before seeding—BS), all the herbicide treatments which followed this basal treatment and metribuzin 285 g/ha (alone) resulted in a significant reduction in grain yield across all the varieties. Application of metribuzin® 187.5 g, flumetsulam® 20 g and isoxaflutole® 75 g + metribuzin 142.5 g/ha as IPP on top of the basal simazine resulted in a further significant reduction in yield of Genesis 836, Sonali and Genesis 510, respectively, as compared as to simazine 1 kg a.i./ha alone. Diuron 1 kg a.i./ha was safe to all the varieties and isoxaflutole 75 g/ha to Genesis 836 and Sonali. Basal simazine followed by diuron 750 g a.i./ha IPP was significantly lower yielding than diuron 1 kg a.i./ha (BS) alone, but it was on a par with basal simazine 1 kg a.i./ha.
- Grain yield of all the varieties registered a significant positive correlation with the plant population recorded 9 WAT. Sonali grain yield also had a significant positive correlation with its plant height (0.752).
- In a similar trial under comparatively drier conditions at Mingenew during 2007 (June–November rainfall = 216 mm), no negative effect on plant population and growth and development of crop plants was recorded for soil applied herbicides like simazine. Grain yield was very low due to dry conditions.
- Simazine and metribuzin are soil active and residual herbicides. Frequent and heavy rainfalls (6–7 days) during the last week of June and whole of July might have activated the pre-emergent herbicides to their full potential. It is also likely that simazine and metribuzin might have leached through seeding slots into the root zone of shallow seeded chickpea varieties, resulting in loss of plant population and ultimately in grain yield. Crop selectivity/tolerance is based on physical separation of these herbicides from chickpea roots. Simazine and metribuzin are group C herbicides and affect photosynthesis in plants. These herbicides do not affect crop emergence adversely, but crop seedlings die after absorbing a lethal dose due to starvation. Interestingly, diuron is more soluble than simazine, but it was much safer than simazine in this trial.
- Interaction of shallow seeding x soil active and residual herbicides x frequent heavy rainfalls during early crop growth stages seems to be the main cause of severe crop damage from herbicides in this trial. Thus, it is suggested to seed the crop at the recommended seeding depth of 5–8 cm and if heavy rainfalls are expected after seeding, within couple of weeks, use lower rates of soil active herbicides. These results also indicate that care is needed to ensure good separation between the seed and herbicide. This will be affected by the dynamics of soil and water movement in the seed bed and the geometry of the seeding process.

KEY WORDS

Desi chickpea, herbicide, tolerance, grain yield

ACKNOWLEDGMENTS

We gratefully acknowledge GRDC for funding the project and Geraldton RSU for technical assistance.

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Paper reviewed by: John Holmes

Table 1 **Effect of herbicides on plant population, plant height and grain yield (% of untreated control) of chickpea varieties at Mingenew (08CH41)**

No	Herbicides (Rate a.i./ha)	Timing	Plant population—3 WAT			Plant population—9 WAT			Height	Grain yield		
	Varieties		Gen. 510	Gen. 836	Sonali	Gen. 510	Gen. 836	Sonali	Sonali	Gen. 510	Gen. 836	Sonali
0	**Untreated control** **Plant population (m^{-2}), Plant height (cm), Yield (kg/ha)**		**100** **(52)**	**100** **(43)**	**100** **(50)**	**100** **(54)**	**100** **(60)**	**100** **(56)**	**100** **(32)**	**100** **(1009)**	**100** **(1129)**	**100** **(863)**
1	Simazine 1 kg (*)	Before seeding (BS)	105	79	98	**71**	**74**	**79**	96	**70**	**73**	**78**
2	Diuron 1 kg		98	98	100	92	94	102	96	123	103	119
3	Isoxaflutole 75 g	Immediately Post Plant (IPP)	92	112	98	95	92	92	97	**75**	89	121
4	Metribuzin 285 g		107	107	104	**73**	**65**	**74**	**74**	**56**	**69**	**63**
5	Isoxaflutole 75 g + Metribuzin 214 g	"	143	115	125	99	93	99	**84**	**64**	**74**	101
6	(*) Isoxaflutole 75 g	(*)-BS fb IPP	112	102	91	**69**	**71**	**77**	**85**	**73**	**81**	**63**
7	(*) Metribuzin 187.5 g	"	98	74	104	**56**	**52**	**77**	**74**	**54**	**53**	**60**
8	(*) Diuron 750 g	"	91	95	104	**62**	**69**	**80**	**87**	**61**	**75**	**73**
9	(*) Isoxaflutole 75 g + Metribuzin® 142.5 g	"	91	101	106	**64**	**69**	**44**	**77**	**27**	**60**	**46**
10	(*) Flumetsulam® 20 g	(*)-BS fb 4–6 nodes	84	115	91	**71**	**73**	**78**	**84**	**66**	**52**	**57**
l.s.d. (0.05) Herbicides v/s Untreated Control			26	31	26	24	26	19	9	16	12	17
l.s.d. (0.05) Herbicides v/s Herbicides			26	31	25	30	32	24	9	21	15	20
CV (%)			19	23	18	27	28	20	7	18	12	16

Gen. = Genesis; WAT = Weeks after pre-emergent herbicide treatments application; a.i. = Active ingredient; (*) = Simazine 1 kg a.i./ha; and fb = followed by:

Figures in **bold** are significantly lower yielding than the untreated control.

Products used: Broadstrike® = flumetsulam (800 g/kg); Balance® = isoxaflutole (750 g/kg); Lexone® = metribuzin (750 g/kg); Simazine 500 g/L and Diuron 500 g/L.

Herbicide tolerance of new wheat varieties

Harmohinder Dhammu[1], Research Officer and **David Nicholson**[2], Technical Officer, Department of Agriculture and Food, Western Australia
[1]Northam and [2]Geraldton

KEY MESSAGES

- The new wheat varieties—Axe, Bumper, Espada, Fortune, Gladius and Magenta showed good tolerance to a range of commonly used herbicides/mixtures.
- Eighteen of the twenty nine treatments tested caused a significant yield reduction in the new short season variety Zippy.
- The herbicides Dual® Gold, Ally®, Hussar® and Kamba® caused a yield reduction in many of the varieties in the trial.
- The data presented here are first results for Axe, Bumper, Espada, Fortune, Gladius, Magenta and Zippy in WA and further testing is required to confirm the results.

AIM

To evaluate the herbicide tolerance of recently released wheat varieties.

METHOD

A field trial was laid out in criss-cross design under weed free conditions at Mullewa Research Station. Nine wheat varieties (Axe, Bumper, Espada, Fortune, Gladius, Janz, Magenta, Zippy and Wyalkatchem) were sown on 11 June 2008 on a red loamy soil (pH 6.2 measured in $CaCl_2$) with three replications. The varieties were sown 3 cm deep in 10 m wide parallel randomized strips. Variety treatments were sown at 75 kg/ha using a combine with knife points and press wheels. Agstar Extra was applied at 70 kg/ha with the seed. The variety Janz and couple of common herbicide treatments were included in all the GRDC funded wheat herbicide tolerance trials nationally to determine herbicides x genotype x environment interactions.

A range of herbicide treatments (Table 1) were applied randomly in three meter wide strips across the variety strips before crop seeding at either seeding (10 and 11 June), at 2–3 leaf stage (1 July), 3–4 leaf stage (6 July) or 5–6 leaf stage (23 July). Every 9th plot was kept as an untreated control to assess the spatial variability. At the time of pre-emergent herbicide treatments application (11 June), gravimetric soil moisture content at 0–10 depth was 6.4% and within 5 days of these treatment being applied the trial received 5.6 mm of rain. Plant numbers were recorded from two randomly selected 50 cm x 50 cm quadrates per plot (24 July) to determine the effect of pre-emergent herbicide treatments on plant establishment. All plots were also assessed for visual injury in terms of leaf spotting, yellowing, height and biomass reduction at 2–4 weeks after each treatment application and again at heading stage. Injury was assessed in a 0 to 100% range, where 0 = no visible injury and 100 = complete plant death (24 June, 14 July, 24 July, 6 August and 20 October). An application of Tilt® (300 mL/ha) was sprayed over the trial for yellow spot control in early August. The trial was harvested on 12 November 2008 (harvest plots of 10 m X 1.8 m). Grain yield data were analysed using Genstat (REML spatial analysis).

Total rainfall from June to November at Mullewa was 129.6 mm. Rain fell every month (≥ 5.2 mm) between June and October with the wettest month in July (50% of the total rainfall with 17 rainy days).

RESULTS AND DISCUSSION

- Triflur® X reduced the plant establishment of Espada significantly and biomass of all the varieties slightly (5%). This treatment resulted in significant yield loss in Bumper and Zippy only. Stomp® reduced the yield of Axe significantly without any visual effects.
- Dual® Gold 250 mL/ha resulted in significant yield loss in Fortune, Gladius and Zippy. Addition of Diuron 1 L to Dual® Gold 250 L/ha resulted in a significant improvement in crop safety for Fortune and Gladius, but not of Zippy.

- Jaguar® and Broadside® each at 1 L/ha caused slight spotting (10–15%) of the leaves across all the varieties. Broadside® also caused dropping leaves in all the varieties, but a yield reduction was only recorded for Zippy.
- Cheetah® Gold 1 L/ha resulted in slight spotting/yellowing (10–15%) of the leaves and an estimated 10% biomass reduction across all varieties during early crop growth stages. This treatment resulted in a significant yield loss in Magenta and Zippy only.
- Ally® 7 g/ha caused differential yellowing and biomass reduction in the different varieties and Axe appeared to be the most affected during early crop growth stages. Interestingly, a significant yield reduction was recorded only for Espada, Gladius, Wyalkatchem and Zippy.
- Achieve® WG 380 g, Achieve® 200 g + Hoegrass® 200 mL, Tigrex® 1 L, Diuron 0.35 L + MCPA 0.4 L , Paragon® 0.5 L and MCPA (amine) 2 L/ha caused a significant yield reduction in Zippy only, where as Glean® 20 g/ha caused in significant yield reduction in Zippy and Wyalkatchem, Monza® 25 g and Buctril® MA 1.4 L/ha caused significant yield reduction in Wyalkatchem, Atlantis® 0.33 L/ha caused significant yield reduction in Axe and Zippy, Hussar® 200 g/ha caused significant yield reduction in Bumper, Fortune, Janz and Zippy and Eclipse® 5 g + MCPA 0.5 L/ha caused significant yield reduction in Espada and Zippy. All of these significant yield reductions were recorded without any noticeable visual negative herbicide effects.
- Kamba® caused drooping leaves/flaccidity symptoms across all the varieties and resulted in a significant yield loss in Axe, Fortune, Gladius, and Zippy.
- 2,4–D amine 625 1.3 L/ha resulted in more ear head deformities in Bumper (15%) and Fortune (10%) compared to Wyalkatchem (3%). A significant yield loss was recorded in Fortune and Zippy only. Interestingly, 2,4–D LV ester 680 (xtra) 0.8 L/ha was safe on all varieties tested.
- Timing of phenoxy herbicides like MCPA and 2,4–D is critical as they often produce morphological abnormalities in vegetative parts and the ear. Product label recommendations are based on the number of leaves on the main stem, however wheat is most sensitive to phenoxy herbicides at the double ridge stage of ear development (the point at which the ear first starts to form). Labels do not take into account differences in the timing of ear development between varieties. Previous observations indicate that stress during early crop growth stages (e.g. moisture stress) can also affect internal ear development rates. Product labels state that MCPA LV Ester up to 0.5 L/ha can be used from 3 leaf stage to flag leaf just visible (Z13–Z33) and from 0.5 L to 2.1 L/ha between Z15–Z33. 2,4–D Amine 50% up to 1.6 L and 2,4–D LV Ester 680 up to 0.8 L/ha can be used from Z15–Z33. Previous research in WA indicates that the safer timing of application of higher rates of phenoxy herbicides in Carnamah and Calingiri starts from Z15.8–Z16.5 and Z16.7–Z17.8 respectively. Bumper and Fortune are similar in maturity to Carnamah and Calingiri, respectively. Therefore delaying application of higher rates of phenoxy herbicides on Bumper until 5.8–6.5 leaves and Fortune until 6.7–7.8 leaves is advised to avoid ear deformities and yield loss (despite labels stating 5 leaves on main stem). Most of the varieties including Bumper and Fortune had 5.5 leaves on the main stem when the Z15–Z16 treatments were applied.
- The yield loss in Gladius from the Ally® and Kamba® (dicamba) treatments is consistent with South Australian trial results (http://www.nvtonline.com.au/herbicide-tolerance).

KEY WORDS

wheat, herbicide, tolerance, grain yield

ACKNOWLEDGMENTS

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Paper reviewed by: Steve Penny

Table 1 **Effect of herbicides on grain yield (% of untreated control) of wheat varieties at Mullewa in 2008**

No	Herbicides (Rate/ha)	Axe	Bumper	Espada	Fortune	Gladius	Janz	Magenta	Zippy	Wyal.
0	**Untreated control** ***Grain yield—kg/ha***	**100** ***2659***	**100** ***2241***	**100** ***2619***	**100** ***2717***	**100** ***2802***	**100** ***2429***	**100** ***2429***	**100** ***2650***	**100** ***2753***
1	Logran B Power® 50 g	100	97	105	99	102	100	101	97	103
2	Stomp® 330 1.8 L	**94**	98	97	102	103	102	98	96	102
3	Triflur® X 3 L	93	**91**	95	95	99	98	94	**91**	101
4	Dual® Gold 0.25 L	99	97	98	**89**	**94**	99	101	**93**	103
5	Diuron 1 L + Dual® Gold 0.25 L	97	93	94	105	101	97	99	**93**	97
6	Boxer® Gold 2.5 L	102	103	107	97	102	95	95	97	104
7	Glean® 20 g	98	106	97	97	97	104	100	**94**	**94**
8	Axial® 0.3 L	97	97	99	99	10o1	105	98	100	102
9	Jaguar® 1 L	100	94	106	97	99	100	97	98	99
10	Monza® 25 g	98	104	94	100	102	101	102	96	**94**
11	Hoegrass® 375 2 L	98	95	95	103	99	102	101	98	95
12	Cheetah® Gold 1 L	100	99	98	97	101	100	**93**	**91**	98
13	Hoegrass® 200 mL +Achieve® 200 g	102	107	106	98	100	99	102	**93**	102
14	Achieve® WG 380 g	100	106	102	100	102	103	101	**95**	99
15	Ally® 7 g	98	100	**93**	102	**94**	103	97	**92**	**92**
16	Atlantis® OD 0.33 L	**95**	103	106	94	101	101	100	**90**	103
17	Broadside® 1 L	97	101	104	102	100	106	105	**94**	98
18	Hussar® 200 g	96	**91**	95	**93**	99	**93**	96	**92**	102
19	Tigrex® 1 L	99	101	104	94	99	97	95	**93**	100
20	Buctril® MA 1.4 L	99	103	98	101	105	110	102	98	**94**
21	Affinity® 50 g + MCPA 0.5 L	103	106	102	98	100	100	107	98	102
22	Precept® 300 1 L	101	103	105	107	102	102	108	99	101
23	Eclipse® 5 g + MCPA LVE 0.5 L	97	100	**93**	97	100	102	98	**95**	95
24	Diuron 0.35 L + MCPA (Amine) 0.4 L	96	106	98	97	103	100	98	**93**	103
25	Paragon® 0.5 L	101	103	100	97	99	100	105	**92**	101
26	MCPA amine 50% 2 L	101	97	97	95	98	99	99	**89**	97
27	2,4–D amine 625 1.3 L	101	100	102	**90**	99	104	100	**92**	102
28	2,4–D LV ester 680 0.8 L	102	95	97	95	105	95	95	100	96
29	Kamba® 500 0.5 L	**86**	94	95	**91**	**93**	94	94	**92**	101
l.s.d. (0.05) Herbicides v/s Untreated Control		5	8	7	7	5	7	7	5	6
l.s.d. (0.05) Herbicides v/s Herbicides		6	10	9	9	7	8	9	7	8
CV (%)		5	8	6	7	5	6	7	6	6

Wyal. = Wyalkatchem.

Treatments 1–6 applied before seeding the crop, 7–13 at Z12–Z13, 14–24 at Z13–Z14 and 25–29 at Z15–Z16.

Treatment 1 was applied with Hasten® 0.5% v/v, 7 + BS® 1000 0.1%, 8 + Adigor® 0.5%, 10 + DC Trate® 2% v/v, 13 and 14 + Supercharge® 0.75%, 12, 16 and 22+ Hasten® 1.0%, 11, 15 and 20 + BS® 1000 0.25%, 23 + Uptake® oil 0.5%.

Figures in **bold** are significantly lower yielding than the untreated control.

PARAGON plus Bromicide 200: a triple mode-of-action approach to combating wild radish, *Raphanus raphanistrum*

Mike Jackson and **Bill Campbell**, Nufarm Australia Limited

KEY MESSAGES

Heightened tolerance of Group I and Group F herbicides is becoming an increasing problem in wild radish populations in the wheat belt. Though a reason for concern, these populations are still relatively easy to control.

The development of stacked * (Group F+I) resistance is of far greater concern as it has the potential to negate a number of key herbicide options currently in use. This threat will increase unless robust control measures are proactively implemented by growers and advisors to manage Group I and Group F resistance and reduce the need for late crop 'rescue' treatments of 2,4–D.

A triple mode-of-action (Group F+I+C) approach to control wild radish is a robust control measure, providing a treatment with various dual-mode (Group F+I, Group F+C and Group I+C) mixes that caters for the potential presence of both Group F and Group I resistant plants in a population.

While Paragon plus Bromicide 200 treatments offer excellent, reliable performance on populations already showing advanced levels of Group F and Group I resistance, they primarily serve as a means to combat the onset of resistance to these groups and thus sustain the use of Group F and Group I herbicides.

INTRODUCTION

Western Australian farmers face an unprecedented threat from herbicide-resistant wild radish, a highly competitive weed distributed over most of the wheat belt. Of particular concern is the shift in tolerance towards phenoxy (Group I) chemistry, a group that forms the basis of most broadleaf weed control options in winter cereals. Farmers and advisors frequently deal with the challenge of controlling populations of wild radish with an unknown resistance status. This can result in incomplete control and the need to re-treat paddocks posing a severe threat to phenoxy chemistry as the rescue or salvage treatments are normally 2,4–D dependent.

AIM

Develop the use of Paragon plus Bromicide 200 to combat resistance to Group I (and Group F) in wild radish.

METHOD

The program was initiated in 2005 and has evolved each year since. As a result methods used have consistently been modified and refined. Fifteen trial sites (2006–2008) contribute to the work. Suitable wild radish populations were identified with the assistance of farm consultants and reseller agronomists and the cooperation of growers, the focus being on targeting wild radish populations thought to be harder to control than in previous years.

Treatments for all trials were applied at 75 L water/ha using a five-nozzle hand held boom and PET bottle system pressurised by LPG. In 2006, XR11001 flat fan nozzles were used, calibrated to a nozzle output of 300 mL/min (at around 175 kPa) and applied at a walking speed of 4.8 km/h. In order to achieve a coarser spray, these nozzles were replaced by TurboT110–01 in 2007, while using the same calibration. AirMix110–01 nozzles were used in 2008 and the calibration changed to a nozzle

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* **Stacked resistance:** A form of multiple resistance where plants in a population independently develop resistance to herbicides with different modes of action, and then through co-existence eventually interbreed to produce individual plants resistant to more than one herbicide groups (see example: S Diebold and F Tardif. 2006).

output of 400 mL/min (at around 260 kPa) and a walking speed of 6.42 km/h. All trials were small plot (2.5 m x 10 m) with three replicates, and included twenty to twenty-five treatments.

Details of crop age and weed age and size, as well as weed population density, were collected at application, the target application window being weed age and size—loosely defined at 15 cm dm or smaller and normally associated with the 4–6 leaf stage.

Visual per cent control of wild radish was estimated at approximately two, four and eight weeks after application, and surviving plants counted at the eight week assessment. At some sites additional assessments were conducted out to 12–14 weeks after application.

Herbicide resistance screening

Field studies were conducted immediately adjoining primary Paragon plus Bromicide 200 trials. These studies evaluated the performance of Group I (using LVE MCPA), Group F (using experimental EC formulations of diflufenican and picolinafen) and Group C (using Bromicide 200) at elevated rates of up to four times the top label recommendation. At sites where this evaluation was combined in single trials with the tank mix work, rates were confined to label recommendations.

In 2008 similar studies were introduced evaluating the performance of the various two-way group combinations, namely Groups F+I (using Paragon), Groups F+C (using picolinafen EC and Bromicide 200) and Groups C+I (using Bromicide MA) at elevated rates. In earlier years and in all combination trials these treatments were included at label rates only.

Wild radish seed collected from untreated areas in and around 2007 trial sites was sent to Plant Science Consulting (PSC) for glass house investigation against known sensitive populations. Seed was collected from 2008 trial sites but has yet to be examined. 2006 sites were not subjected to this investigation.

Without the ability to directly compare performance against a known sensitive population, field data only permitted an informed estimate of the likely resistance status of populations to be made. The likely status of Group I was considerably easier to gauge than Group F and Group C where plant age was a compounding influence.

Paragon plus Bromicide 200 evaluation

Tank mixes of Paragon at 250, 375 and 500 mL/ha and Bromicide 200 at 500, 750, 1000 and 1250 mL/ha were variably examined during the course of this investigation. The low rate of Paragon was discontinued after 2007 as it is considered inappropriate for controlling wild radish populations with any degree of heightened tolerance of Groups F and I. The inclusion of tank mixes with Bromicide 200 at 1250 mL/ha was limited to 2008 trial work and was more for theoretical reasons than practical.

The core treatments have been Paragon at 375 and 500 mL/ha with Bromicide 200 at 500 and 750 mL/ha and these treatments form the focus of this paper. The significance of these rates is that the treatment in effect contains three commonly used dual-MOA products, namely Paragon, Bromicide MA and a Jaguar-like mix, each at rates similar to current label recommendations for these products, and each thereby effectively ‘protecting’ the third mode of action.

Performance of Picolinafen EC

In 2007 four dose response trials were conducted comparing the performances of emulsifiable concentrate formulations of picolinafen (PLF EC) and diflufenican (DFF EC), both experimental formulations exactly equivalent to Paragon and Nugrex but lacking MCPA, and their corresponding non-EC products, Sniper WG and Brodal Options.

RESULTS AND DISCUSSION

Herbicide resistance screening

The assumed resistance status of each wild radish population investigated is shown in Table 1. Eight of the fifteen sites showed abnormally weak responses to LVE MCPA in field studies, of which the Bindi Bindi and Kellerberrin-2 sites were most pronounced, the latter barely causing epinasty at

500 mL/ha. PSC rated the Group I resistance status of the 2007 populations as follows—Narrogin: 15 per cent (R), Hyden: 35 per cent (RR), Coorow: 25 per cent (R) and Meenaar: 20 per cent (R) suggesting that field work could be missing subtle, early tolerance shifts in some populations even though plants are well controlled.

The performance of Group F may not accurately reflect the resistance status of all populations as some sites were treated when plants were older than recommended for optimal activity, and in the case of Hyden when plants were suffering moisture stress. PSC rated the Group F resistance status of the 2007 populations as follows—Narrogin: 25 per cent (R), Hyden: 30 per cent (R), Coorow: 25 per cent (R) and Meenaar: 15 per cent (R) again suggesting that field work could be missing subtle, early tolerance shifts in some populations.

Bromoxynil is presumed sensitive though performance was frequently weak to poor as a result of plants being too large at application. PSC determined all 2007 populations as sensitive.

The weaker performance of Paragon at Bindi Bindi, Kellerberrin-2 and Hyden (and possibly also at Cunderdin) suggests the presence of stacked (Group F+I) resistance especially at the two former sites, and this paper formally proposes the phenomenon as the likely cause of this performance.

Table 1 **Categorisation of the herbicide resistance status of wild radish populations from field studies**

Site, year	MCPA LVE 250 g a.i./ha (I)	MCPA LVE 500 g a.i./ha (I)	DFF EC/PLF EC 19–25 g a.i./ha (F)	DFF EC/PLF EC 37.5–50 g a.i./ha (F)	Bromoxynil 188 - 200 g a.i./ha (C)	LVE MCPA + Bromoxynil 187 + 187 – 250 + 250 g a.i./ha (C+I)	MCPA + PLF EC 250 + 25 g a.i./ha (F+I)	PLF EC/WG + bromoxynil 25 + 250 g a.i./ha (F+C)	Weeks after application
1. Dandaragan: 2006	S	S	S	S	-	S	S	S	8
2. Bindi Bindi: 2006	RRR	RR	R	S	-	RR	R	R	5
3. Southern Brook: 2006	R	R	RR	-	-	R	S	S	7
4. Arrino: 2006	R	S	R	-	-	R	S	S	7
5. New Norcia: 2006	S	S	RR	-	-	R	S	S	7
6. Narrogin: 2007	S	S	S	S	S	S	S	-	5
7. Hyden: 2007	RR	R	R	S	S	RR	R	-	8
8. Coorow: 2007	S	S	R	S	S	R	S	-	8
9. Meenaar: 2007	S	S	S	S	S	S	S	-	8
10. Kellerberrin-1: 2008	S	S	S	S	S	S	S	S	9
11. Cunderdin: 2008	RR	R	R	S	S	RR	S	S	9
12. Bolgart: 2008	S	S	S	S	S	S	S	S	5
13. Kellerberrin-2: 2008	RRR	-	RR	-	S	RRR	RR	S	9
14. Kukerin-1: 2008	RR	-	R	-	S	RR	S	S	5
15. Kukerin-2: 2008	R	-	S	-	S	RR	S	S	8
% Control category S *	95–100	95–100	90–100	90–100		97–100	97–100	97–100	
% Control category R	80–95	80–95	75–90	75–90		90–97	90–97	90–97	
% Control category RR	50–80	50–80	50–75	50–75		80–90	80–90	80–90	
% Control category RRR	0–50	0–50	0–50	0–50		0–80	0–80	0–80	

* Categories are an arbitrary judgement based on degree of deviation from expected level of control, and the performance at elevated rates of herbicide.

Paragon plus Bromicide 200 evaluation

The performances of treatments of Paragon, with and without Bromicide 200, are shown in Table 2. Paragon alone at 500 mL/ha provided excellent to absolute control of eleven of the fifteen populations treated. Five of these sites (Dandaragan, Narrogin, Meenaar, Kellerberrin-1 and Bolgart) are considered to be largely sensitive to Group F and Group I, while six (Southern Brook, Arrino, New Norcia, Coorow, Kukurin-1 and Kukurin-2) are thought to have early signs of heightened tolerance of either Group I, or Group F, or both. The inclusion of Bromicide 200 in a tank mix with Paragon essentially provided no obvious benefit at these sites though overall reliability was improved.

At the remaining four sites (Bindi Bindi, Kellerberrin-2, Hyden and Cunderdin) where heightened tolerance of Group I and Group F appeared advanced and the presence of stacked (Group F+I) plants likely, Paragon alone performed below expectation. This was especially true for the Bindi Bindi and Kellerberrin-2 populations. At these sites the addition of Bromicide 200 to Paragon provided a distinct improvement in performance, the Hyden site being the only one where the treatments could not be separated from Paragon alone in individual trial analysis.

Table 2 **Per cent control of wild radish at 5–9 WAA using Paragon, with and without Bromicide 200**

Site, year	Weeks after application	Paragon 375 mL/ha	Paragon 500 mL/ha	Paragon 375 mL/ha + 500 mL/ha Bromicide 200	Paragon 375 mL/ha + 750 mL/ha Bromicide 200	Paragon 500 mL/ha + 500 mL/ha Bromicide 200	Paragon 500 mL/ha + 750 mL/ha Bromicide 200	ANOVA F prob.
1. Dandaragan: 2006	8	100 a	100 a	100 a	100 a	100 a	100 a	-
2. Bindi Bindi: 2006	5	**78 b**	**84 b**	98 a	97 a	99 a	99 a	0.001
3. Southern Brook: 2006	7	100 a	100 a	99 a	100 a	100 a	100 a	0.1566
4. Arrino: 2006	7	95 a	100 a	100 a	99 a	100 a	100 a	0.2619
5. New Norcia: 2006	7	100 a	100 a	100 a	100 a	100 a	100 a	-
6. Narrogin: 2007	8	99 a	98 a	98 a	99 a	100 a	100 a	0.6
7. Hyden: 2007	8	92 a	97 a	95 a	96 a	97 a	97 a	0.1892
8. Coorow: 2007	8	100 a	100 a	100 a	100 a	100 a	100 a	-
9. Meenaar: 2007	8	100 a	100 a	100 a	100 a	100 a	100 a	0.5875
10. Kellerberrin-1: 2008	9	97 a	99 a	99 a	100 a	100 a	100 a	0.6063
11. Cunderdin: 2008	7	**95 c**	**98 bc**	100 ab	100 ab	100 a	100 a	0.0039
12. Bolgart: 2008	5	100 a	100 a	100 a	100 a	100 a	100 a	-
13. Kellerberrin-2: 2008	9	**50 b**	69 ab	80 a	81 a	-	88 a	0.0162
14. Kukerin-1: 2008	5	100 a	100 a	100 a	100 a	-	-	-
15. Kukerin-2: 2008	8	100 a	100 a	100 a	100 a	-	-	-

Letters against means indicate statistical separation (p = 0.05) DNMRT.

Mean % control for Sites 2,3,4,11 and 13: detransformed from X = Arcsine square root per cent.

Sites: 1, 3, 4, 5, 6, 8, 9, 13, 15—control data based on surviving wild radish plants expressed as a per cent reduction from the number in the untreated Check. Sites: 2, 7, 10, 11, 12, 14—per cent control data based on visual observation.

Multi-trial analysis (Table 3) indicated that Paragon at 500 mL/ha provided a significantly improved performance over 375 mL/ha at the twelve sites included in the examination (three sites were excluded because of missing treatments). The addition of Bromicide 200 to both rates of Paragon significantly improved performance over each rate of Paragon alone.

While the analysis does not demonstrate an advantage in increasing the rate of Bromicide 200 from 500 mL/ha to 750 mL/ha, it seems logical to assume that the rate of bromoxynil would need to increase as the presence of stacked (Group F+I) resistance increases in a population, and some populations may require rates up to 1000–1250 mL/ha. There are limited data that support this assumption.

The only effective means of combating the development of herbicide resistance in weeds chemically is to prevent seed set in the generation that is treated. As this is practically unrealistic the aim should be to achieve as close as possible to total prevention. In this research Paragon alone at 375–500 mL/ha achieved at least 98 per cent control on around seventy per cent of plots assessed (the balance of plots averaging 82 per cent control), while over eighty-five per cent of plots assessed achieved this level of control when Bromicide 200 was added (the balance of plots averaging 90 per cent control).

With a number of new herbicides available to growers, all in excess of $20 per hectare, the additional cost of 500–750 mL/ha Bromicide 200 to Paragon is both affordable and most worthwhile given the scenario where the precise resistance status of most paddocks is unknown. The inclusion of Bromicide 200 becomes a proactive safeguard against the unknown providing a more reliable level of control than Paragon alone (which is generally excellent in itself but under severe threat).

Table 3 **Multi-trial analysis of the per cent control of Paragon plus Bromicide 200 treatments against wild radish**

A. Response to the dose of Paragon*

Bromicide 200	Paragon	Mean % control
0, 500, 750	375	98.04 a
0, 500, 750	500	99.59 b
ANOVA F prob.		< 0.0001

B. Response to the dose of Bromicide 200*

Paragon	Bromicide 200	Mean % control
375, 500	0	97.37 a
375, 500	500	99.52 b
375, 500	750	99.45 b
ANOVA F prob.		< 0.0001

C. Response to individual treatments*

Paragon	Bromicide 200	Mean % control
375	0	95.91 a
500	0	98.51 b
375	500	98.87 b
375	750	98.78 b
500	500	99.90 c
500	750	99.85 c
ANOVA F prob.		< 0.0001

* Excludes Sites 1, 5, 8 and 12 (all 100%).

D. Response to the location of the trial

WAA	Location	Mean % control
5	2. Bindi Bindi	94.48 a
8	7. Hyden	95.80 a
7	4. Arrino	99.12 b
8	6. Narrogin	99.26 b
9	10. Kellerberrin-1	99.42 b
7	11. Cunderdin	99.56 bc
7	3. Southern Brook	99.88 bcd
8	9. Meenaar	99.97 cd
8	1. Dandaragan	100 d
7	5. New Norcia	100 d
8	8. Coorow	100 d
5	12. Bolgart	100 d
ANOVA F prob.		< 0.0001

E. Sites excluded from multi-trial analysis (missing trts)

WAA	Location	Mean % control
9	13. Kellerberrin-2**	90.22
5	14. Kukerin-1***	100
8	15. Kukerin-2***	100

** Missing Paragon 500 mL/ha + 500 mL/ha Bromicide 200.

*** Missing Paragon 500 mL/ha + 500 mL/ha Bromicide 200 and Paragon 500 mL/ha + 750 mL/ha Bromicide 200.

Letters against means indicate statistical separation (p = 0.05) DNMRT, within responses.

Mean % control: detransformed from X = Arcsine(Sqrt(x/100)).

Performance of Picolinafen EC (compared with Diflufenican EC)

Both Picolinafen EC and Diflufenican EC were consistently more active on wild radish than their non-EC counterparts at similar dose rates at all sites, though these differences were not always significant in individual trial analysis. Picolinafen was also more active than diflufenican, with both formulations consistently providing stronger activity than the corresponding diflufenican formulations, though again these differences were not always significant in individual trial analysis (see Table 4 below).

Table 4 **Surviving wild radish (plants per 10 sqm) of various picolinafen and diflufenican treatments 8 WAA**

Trt. code	**Location**	**Narrogin**	**Hyden**	**Coorow**	**Meenaar**
	Wild radish: cot – 5 leaf*	**95%**	**75%**	**25%**	**40%**
	Wild radish: > 5 leaf*	**5%**	**25%**	**75%**	**60%**
	Plants per sqm at appl.	**15**	**80**	**20**	**20**
	Conditions at appl.	**Good**	**Moisture stress**	**Stress before appl.**	**Good**
A	Untreated Check	95 **	85 **	48 **	171 **
B	Picolinafen EC 9.38 g a.i./ha	21 b	43 ab	7 c-f	44 bcd
C	Picolinafen EC 18.75 g a.i./ha	5 c	18 cd	10 b-e	23 de
D	Picolinafen EC 37.5 g a.i./ha	1 d	6 d-g	2 efg	3 g
E	Picolinafen WG 18.75 g a.i./ha	35 a	40 abc	16 a-d	51 abc
F	Picolinafen WG 37.5 g a.i./ha	7 c	16 de	15 a-d	26 cde
G	Picolinafen WG 75 g a.i./ha	1 d	6 d-g	3 efg	6 fg
H	Picolinafen WG 150 g a.i./ha	0 d	3 efg	1 fg	1 g
I	Picolinafen WG 300 g a.i./ha	0 d	0 g	0 g	0 g
J	Diflufenican EC 9.38 g a.i./ha	35 a	66 a	24 ab	58 ab
K	Diflufenican EC 18.75 g a.i./ha	5 c	14 de	23 ab	32 b-e
L	Diflufenican EC 37.5 g a.i./ha	1 d	12 de	6 d-g	17 ef
M	Diflufenican SC 37.5 g a.i./ha	48 a	21 bcd	31 a	83 a
N	Diflufenican SC 75 g a.i./ha	16 b	11 def	16 a-d	52 abc
O	Diflufenican SC 150 g a.i./ha	1 d	8 d-g	19 abc	28 cde
P	Diflufenican SC 300 g a.i./ha	0 d	1 fg	6 d-g	22 de
Trt prob. (F)		0.0001	0.0001	0.0001	0.0001

Letters against means indicate statistical separation (p = 0.05) DNMRT.

Mean % control for all sites: detransformed from X = Square root (x + 0.5).

* Per cent of wild radish population in each category. ** Plants per 10 sqm.

Differences in activity were less apparent at the Narrogin and Meenaar sites that were treated under good conditions when the entire wild radish populations were at or near the optimal age window (the Meenaar population was no older than 6-leaf). At these sites, considered as probably sensitive to Group F (though PSC rated both as showing developing resistance), Picolinafen EC and Diflufenican EC performed according to (label) expectation. At the Hyden and Coorow sites, where plants were suffering or recovering from moisture stress and were (especially in the case of Coorow) considerably beyond the optimal age window, the performance of both products was noticeably weaker.

Table 5 **Multi-trial analysis of the activity of Picolinafen EC and Diflufenican EC on wild radish 8 WAA**

Treatment			**Mean No. of plants per 10 sqm ***	
Code	**Product**	**Dose g a.i./ha**		
A	Untreated control		94.8	j
B	PLF EC	9.375	25.7	gh
C	PLF EC	18.75	13.2	def
D	PLF EC	37.5	2.5	bc
J	DFF EC	9.375	43.9	i
K	DFF EC	18.75	16.9	efg
L	DFF EC	37.5	7.3	cd
ANOVA F prob.			< 0.0001	
BCD	PLF EC	9–37	6.8	
JKL	DFF EC	9–37	11.6	
Sig. of diff. (paired t-test)			0.0006	
CD	PLF EC	18–37	11.8	
KL	DFF EC	18–37	20.1	
Sig. of diff. (paired t-test)			0.0082	

Mean counts detransformed from X = sqrt(x).

* Mean of four trials, n = 12

Treatment			**Mean % control ****			
			Group 1		**Group 2**	
Code	**Product**	**Dose g a.i./ha**	**Coorow Hyden**		**Narrogin Meenaar**	
A	Untreated control		0	a	0	a
B	PLF EC	9.375	68	cde	76	ef
C	PLF EC	18.75	78	ef	91	f-i
D	PLF EC	37.5	95	g-j	99	ijk
J	DFF EC	9.375	32	b	64	cde
K	DFF EC	18.75	69	cde	88	fg
L	DFF EC	37.5	87	fg	96	g-k
ANOVA F prob.			< 0.0001			
BCD	PLF EC	9–37	81.7	b	91	c
JKL	DFF EC	9–37	64.1	a	85	bc
ANOVA F prob.			< 0.0001			

** % control calculated relative to the nearest UTC.

Statistical separation letters apply to means within and between groups and within analyses.

Mean % control: detransformed from X = Arcsine(Sqrt(x/100))

Letters against multiple comparison means indicate statistical separation (p = 0.050) DNMRT.

Multi-trial analysis (Table 5) demonstrated that on average Picolinafen EC (at all three rates as well as at the two higher rates) performed significantly better than Diflufenican EC. The activity of both products was negatively impacted by weed size and environmental conditions. Both products performed significantly better under the favourable conditions prevailing at Narrogin and Meenaar than they did under the unfavourable conditions experienced at Coorow and Hyden. Of importance is that under the unfavourable conditions experienced at Coorow and Hyden Picolinafen EC appeared less affected than Diflufenican EC, suggesting that picolinafen is a more robust Group F herbicide.

These data support a claim that at identical rates picolinafen in Paragon is a more robust Group F component than diflufenican in Nugrex.

SUMMARY AND CONCLUSIONS

Heightened tolerance of Group I and Group F chemistry in wild radish is widespread in the Western Australia wheat belt. It appears to be in its early stages in most areas though more established in northern parts. Most populations appear to be comprised of individuals showing heightened tolerance of either Group I or Group F, and in many cases these plants are co-existing.

The presence of stacked (Group F+I) resistance in a population is an advanced state of resistance and is still relatively uncommon. It is likely to become increasingly evident if the levels of Group F and Group I resistant plants in populations are allowed to increase.

A new, more aggressive and proactive approach to wild radish control must be adopted in order to protect Group F and Group I based herbicides and prolong their availability to growers.

Dual Group F+I treatments (such as Paragon) can achieve excellent control of populations containing individuals showing heightened tolerance of either Group I or Group F, but only when used at robust rates. It is postulated that these products are insufficiently active on individuals with stacked F+I resistance.

This research suggests that picolinafen offers more Group F activity than diflufenican on an equivalent grams active basis. Hence Paragon is a more balanced Group F+I treatment than products containing diflufenican which by inference must be more reliant on the phenoxy component.

The addition of bromoxynil to Paragon can significantly improve performance on populations where heightened tolerance of either Group F or Group I is entrenched or where early stacked (Group F+I) resistance is present. This triple mode-of-action treatment is an excellent means of safeguarding against the possibility that early stacking is occurring in a population and ensuring a consistent performance at a very high level of control.

In this respect the additional cost of Bromicide 200 to create a triple mode-of-action treatment with Paragon is considered worthwhile even though Paragon alone normally achieves a very high level of control.

KEY WORDS

wild radish, stacked resistance, Paragon, Bromicide 200

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Interaction of glyphosate dose, annual ryegrass growth stage and environmental conditions on the performance of glyphosate for control of annual ryegrass

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KEY MESSAGES

- Annual ryegrass tolerates high doses of glyphosate for about a week after emergence.
- The current models overestimate the effects of temperature, water volume, water stress and weed size when young and underestimate the effects of weed size later in the season.

AIMS

To determine the effects of time of application and environmental stress on the glyphosate dose response curve for annual ryegrass (*Lolium rigidum*) control and compare these results with 2 models used to predict an effective dose of glyphosate.

METHOD

Glyphosate 540 g/L as Roundup® PowerMAX was applied by a logarithmic sprayer that delivers a constantly decreasing dose from 2500 mL/ha at the beginning of the plot to 125 mL/ha at the end of the 20 m plot. Treated plots were sprayed once at approximately the 1-leaf (L1), 3-leaf (L3), 6-leaf (L6) or tillering (Til) stages of the annual ryegrass at Esperance and Newdegate or at the first three times at Eradu as shown in Table 1. There were four replicates of each treatment. Visual assessments of the percentage kill of annual ryegrass were taken approximately 2 weeks after spraying at Eradu or in August for the Esperance and Newdegate sites.

Table 1 **Experimental details for three sites in 2008**

Break of season	Newdegate (NRS)	Esperance (Esp)	Eradu (Era)
	20/4/08 (7/4/08)*	14/5/08 (21/4/08)*	18/4/08
L1 Spray date	1/5/08	27/5/08	24/4/08
Ryegrass Stage	1 leaf-3 tiller	1–3 some 6 leaf	1 leaf
Days from break	11	13	6
L3 Spray date	20/5/08	15/6/08	8/5/08
Ryegrass Stage	4 leaf – 6 tillers	6 leaf – tillering	2–3 leaf
Days from break	30	32	20
L6 Spray date	10/6/08	7/7/08	28/5/08
Ryegrass Stage	tillering	tillering	6 leaf
Days from break	51	54	40
Till Spray date	1/7/08	29/7/08	
Ryegrass Stage	tillering	tillering	
Days from break	72	76	

* Figures in brackets indicate an earlier rainfall event that induced a partial germination of annual ryegrass.

The DRC package (Ritz and Streibig 2005) in the R Statistical System was used to fit a standard logistic model to the responses. For Newdegate and Esperance the upper limit was set to 100 per cent control and the lower limit to 0 per cent control and the slope and ED_{50} parameters were estimated by the package. For the Eradu data only the lower limit was constrained to 0 per cent control when no herbicide was applied. An initial model without the times of application was fitted then the times of application were added to determine if this improved the fit. This model was used to determine the ED_{99} and ED_{90} that are the effective dose that provided 99 and 90 per cent control of annual ryegrass respectively.

There are two Australian models for adjusting herbicide doses based on various environmental and other conditions. The first (Model A) is a spreadsheet developed by Minkey and Moore (1998) and the second (Model B) is adapted from the factor adjusted doses model developed by Andrews et al. (2008) for predicting grass selective Group A herbicide doses (Moore and Moore 2008). The predicted doses from Model A were obtained using weather data from a nearby weather station and observations of nutrient status, weed stages and sizes from the experiments. The predicted doses for Model B were obtained by running the model in HerbiGuide with the emergence date, spraying date, weather data, soil type, nutrient status and spray volume specified. Output from these models was compared with the data measured in these experiments (Table 2).

RESULTS

In most cases the dose of herbicide had to be increased by 50–100 per cent to increase efficacy from 90 to 99 per cent.

Application of glyphosate 6 days after the first rains (at Eradu) when the ryegrass was in the half to one leaf stage was not effective even at the highest dose (2500 mL/ha) tested.

At Newdegate and Esperance more annual ryegrass emerged after the first three times of spraying.

Overall, the correlation coefficient between the observed ED_{99} dosages and the dosages predicted using Model A was 0.60 with $p < 0.06$. For Model B the correlation coefficient was better at 0.78 with $p < 0.007$.

Table 2 **The dose in mL/ha of Roundup® PowerMAX (540 g/L) required for 99% and 90% control of annual ryegrass and the dosages predicted by two models for 95–99% control of annual ryegrass**

Site	Treatment (Days after break)	ED_{99} ± s.e.*	ED_{90} ± s.e.*	Model A	Model B
NRS (Newdegate)	L1 (11)	829 ± 154 d	410 ± 44 c	434	600
NRS (Newdegate)	L3 (30)	829 ± 154 d	410 ± 44 c	603	800
NRS (Newdegate)	L6 (51)	829 ± 154 d	410 ± 44 c	1146	800
NRS (Newdegate)	Til (72)	829 ± 154 d	410 ± 44 c	908	880
Esp (Esperance)	L1 (13)	179 ± 18 a	154 ± 9 a	515	400
Esp (Esperance)	L3 (32)	419 ± 163 bc	255 ± 56 b	1411	400
Esp (Esperance)	L6 (54)	597 ± 306 bcd	321 ± 96 bc	1023	320
Esp (Esperance)	Til (76)	559 ± 324 bcd	333 ± 112 bc	1023	120
Era (Eradu)	L1 (6)	> 2500	> 2500	697	NA**
Era (Eradu)	L3 (20)	623 ± 42 d	424 ± 15 c	1023	1500
Era (Eradu)	L6 (40)	1767 ± 140 f	1082 ± 45 e	1705	2000

* Figures followed by the same letter are not significantly different. s.e. = standard error.

** NA = Not applicable.

Newdegate

At Newdegate Research Station, a simple model ignoring the times of application fitted the data just as well as a model with times of application included (Figure 1). So the simple model was used to determine the ED_{99} and ED_{90} shown in Table 2 for Newdegate based on the data.

The predictive Model A underestimated the dose at L1 but was within the confidence interval for the ED_{99} at the other three times of application (Figure 1). The factor adjusted doses (Model B) varied from 600 to 880 mL/ha for this site and were within the confidence interval of the observed data (Figure 2). Model A overestimated the effect of stress at L6 and underestimated the dose at the one leaf stage (L1).

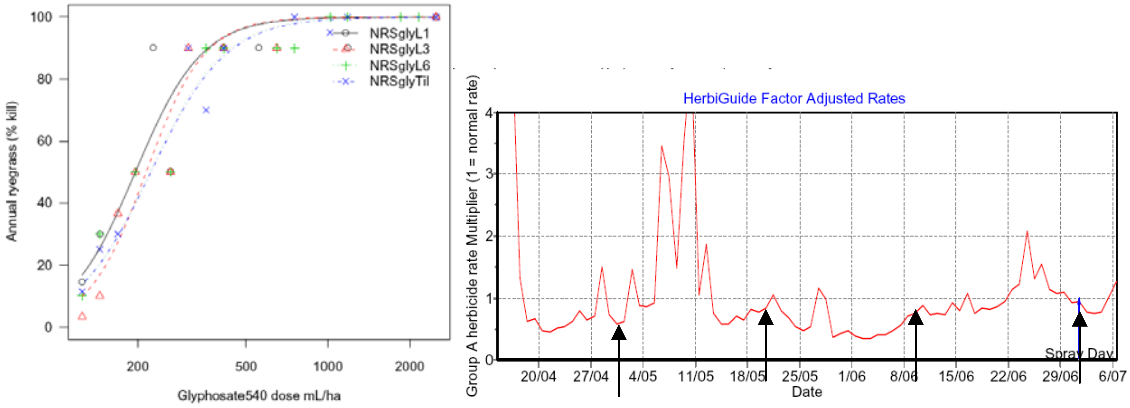

Figure 1 Annual ryegrass response to glyphosate at four times of application at Newdegate Research Station and doses of herbicide predicted by Model B for Newdegate in 2008. Arrows indicate the days when glyphosate was applied. NRSgly1, NRSgly3, NRSgly6 and NRSglyTill = glyphosate applied at 1 leaf, 3 leaf, 6 leaf and tillering stages respectively.

Esperance

At Esperance Downs Research Station, the early application was the most effective and the late application the least. The dose response curve for two latest times of spraying were not significantly different. This was qualitatively similar to Newdegate but there was a greater separation between the dose response curves for the four times of application (Figure 2). Annual ryegrass at the earliest time of spraying, 13 days after the break of season was controlled by much lower rates than predicted by the 2 models. At the later times Model A tended to overestimate the rate glyphosate required for a 99 per cent kill of annual ryegrass and Model B tended to underestimate it especially at the last time of spraying, 76 days after the break.

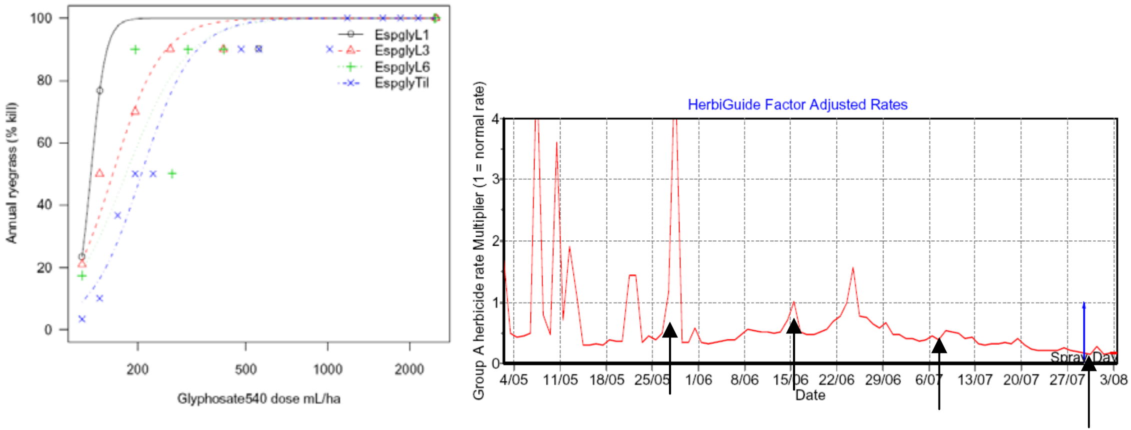

Figure 2 Annual ryegrass response to glyphosate at four times of application at Esperance Downs Research Station and doses of herbicide predicted by Model B for Esperance in 2008. Arrows indicate the days when glyphosate was applied. Espgly1, Espgly3, Espgly6 and EspglyTill = glyphosate applied at 1 leaf, 3 leaf, 6 leaf and tillering stages respectively.

Eradu

At Eradu, the first treatment was applied 6 days after the first rains for the season when the annual ryegrass was in half to one leaf stage. The maximum dose (2500 mL/ha of Roundup Max®) tested only provided 30 per cent control. The response at the 3 leaf stage treatment was similar to other sites. Lack of rain lead to significant water stress by the time of the 6 leaf stage treatments and high doses were required to give good control of annual ryegrass (Figure 3). Both models overestimated the moisture stress and glyphosate doses required at the L3 time of spraying but provided good estimates for the later spraying.

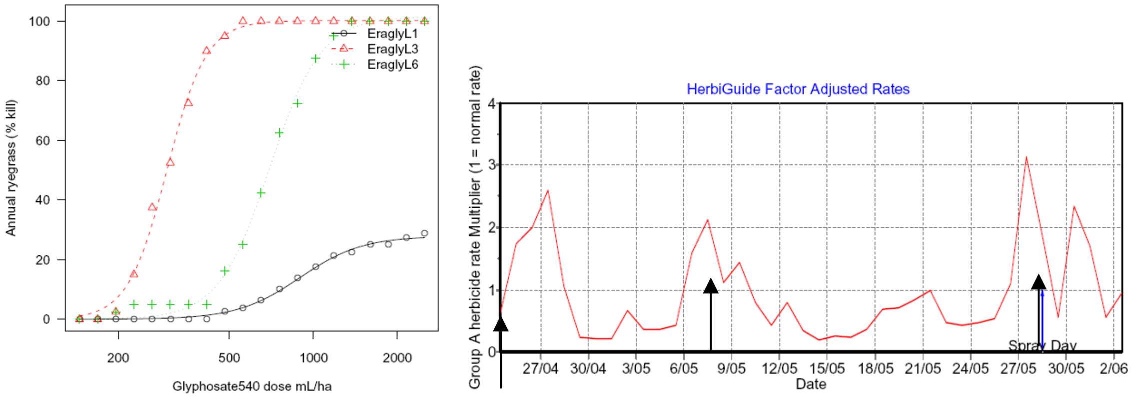

Figure 3 Annual ryegrass response to glyphosate at three times of application at Eradu and doses of herbicide predicted by Model B for Eradu in 2008. Arrows indicate the days when glyphosate was applied. Eragly1, Eragly3, Eragly6 and EraglyTill = glyphosate applied at 1 leaf, 3 leaf and 6 leaf stages respectively.

CONCLUSION

Application of glyphosate soon after emergence is unlikely to provide adequate control of annual ryegrass. The tolerance to glyphosate falls very quickly with doses of glyphosate greater than 2500 mL/ha required 6 days after the break of the season compared to 713 mL/ha 11 days after and 179 mL/ha 13 days after the break. The current models for predicting herbicide rates do not adequately cover this scenario. Model A is a simple spread sheet model and while a good decision aid for picking various situations where much increased doses of glyphosate are required it lacks the accuracy for fine tuning glyphosate rates. Model B was developed for Group A (grass selective) herbicides and has good algorithms for determining daily stress levels, it is over sensitive to temperature fluctuations and under sensitive to growth stage and density of weeds. With larger data sets it could be rewritten to be more useful for predicting glyphosate efficacy. In its current form, Model B is providing reasonable guidance as to when periods of stress occur which will affect the effectiveness Group M (glyphosate) herbicides but it still lacks the accuracy required for general adoption. The main reasons for this are probably the different responses of Group A and Group M herbicides to temperature, water volume and plant size or density.

With the advent of glyphosate tolerant crops it will be possible to apply the glyphosate after the crop has emerged. This will allow farmers to plant their crops immediately after the break of the season and control their annual ryegrass and other weeds two weeks later when they require the minimal dose for control. This should increase farm productivity especially in the short growing season areas by allowing earlier planting, hence greater yields and reduce the amount of glyphosate required for a given level of weed control.

KEY WORDS

annual ryegrass, dose response, environmental stress, glyphosate, growth stage, knockdown herbicide, Lolium, rigidum.

ACKNOWLEDGMENTS

We gratefully acknowledge GRDC for funding the project. We are also thankful to the Research support units of Geraldton, Esperance, and Newdegate. Cooperations from Alex Douglas, Sally Peltzer, David Bowran and other DAFWA weed staff are also gratefully acknowledged.

Project No.: DAW00158

Paper reviewed by: Dr Corey Moore

Metribuzin pre-sowing of lupins

Peter Newman, Department of Agriculture and Food, Western Australia

KEY MESSAGES

Metribuzin pre-sowing of Mandelup lupins is showing potential as a safe option to improve broadleaf weed control in lupins in WA. A minor use permit for this practice exists in NSW and SA. Metribuzin tolerant lupins AZ33 and AZ55 bred using mutagenesis demonstrated poor vigour, poor tolerance of diflufenican and yielded 33 to 40 per cent less than Mandelup.

METHOD

Three lupin varieties were compared in a strip plot design with 3 replicates. Mandelup was compared to two varieties bred by mutagenesis for metribuzin tolerance Tanjil AZ33 and Tanjil AZ55. Property of Bob and Murray Preston. Yellow sandplain soil, 35 km North West of Mingenew. Treatments 1 and 2 sprayed onto dry soil on 23 April 2008. 20mm rain on 28 April. Remaining pre-sowing treatments applied 30 April 2008. Lupins sown into moist soil by cone seeder at 22 cm row spacing on 30 April 2008. Post emergent broadleaf treatments applied 11 June 2008. Visual phyto toxicity ratings conducted 26 June (15 days after broadleaf treatments). Wild radish density assessed by counting a transect 0.7m by 27m long prior to post emergent spraying. Ryegrass assessed by $0.1m^2$ quadrats.

RESULTS

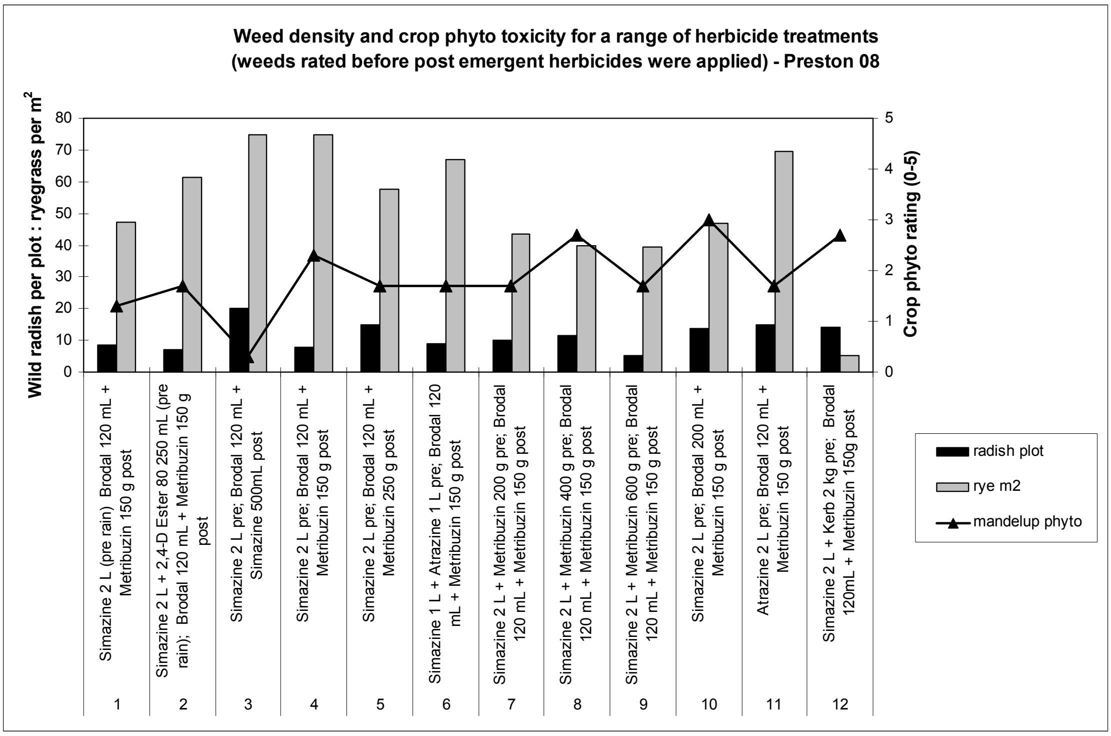

Figure 1 Weed density (wild radish per plot; annual ryegrass/m^2) and crop phyto toxicity rating of Mandelup (rating of 0 to 5 where 0 = no crop phyto and 5 = severe scorching) for a range of herbicide treatments. Weed density measured before post emergent herbicide application. Crop phyto rated after post emergent broadleaf herbicide treatments.

There was no significant difference in wild radish control between treatments ($p > 0.05$). Treatment 12 had a significantly lower ryegrass density than all other treatments ($p < 0.05$). There were significant differences in phyto toxicity between treatments and between varieties ($p < 0.05$). Treatment l.s.d. = 0.96. The average phyto toxicity ratings across all treatments between varieties were Mandelup = 1.86; AZ33 = 2.69; and AZ55 = 3.30; l.s.d. = 0.48. Treatment 10 (200 mL/ha Brodal®) had the highest phyto ratings; Mandelup = 3.0; AZ33 = 4.3; and AZ55 = 4.7; l.s.d. = 0.96.

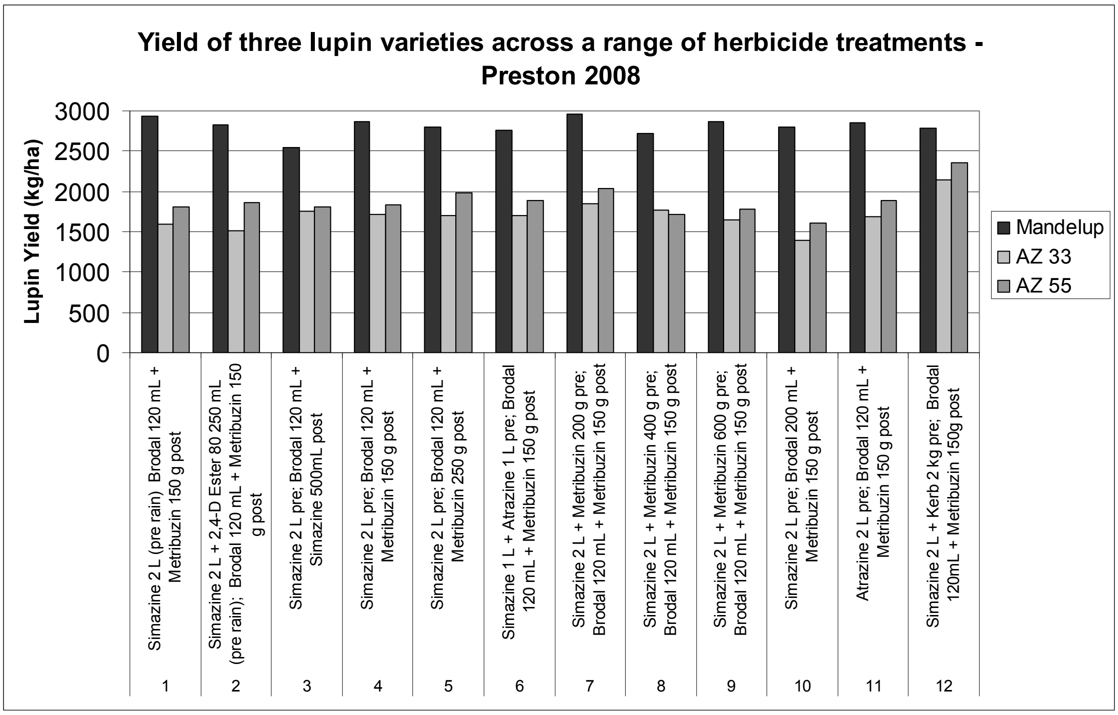

Figure 2 Lupin yield of three lupin varieties for a range of herbicide treatments.

There were significant differences in lupin yield between varieties ($p < 0.05$; l.s.d. = 119 kg/ha). There were significant differences in lupin yield between treatments ($p < 0.05$; l.s.d. = 238 kg/ha).

CONCLUSION

Three years of research now demonstrates that Mandelup lupins have good tolerance of high rates of metribuzin when applied pre sowing. Two years of this research was conducted in very dry growing seasons and further research is required to gain confidence in these results. This trial demonstrates that all lupins had good tolerance of high rates (600 g Lexone/ha) of metribuzin applied pre sowing of lupin but there was no effect on ryegrass control and only a minor effect on wild radish control. Previous research has demonstrated useful suppression of broadleaf weeds. A minor use permit exists in NSW and SA for the use of 300 gai/ha metribuzin pre-sowing of lupins. Future research will focus on extending this permit to Western Australia. Kerb (propyzamide) gave approximately 91 per cent ryegrass control and caused significant crop phytotoxicity. This high level of weed control was aided by excellent soil moisture. Kerb is not registered for use in lupins in Australia. Two treatments were applied prior to opening rain to determine if Simazine incorporated by rain affected weed control. There was no effect of spraying prior to opening rain and 2,4–D ester had no effect on the lupins.

As part of a GRDC funded project, Dr Ping Si used mutagenisis to breed two new cultivars of narrow leaf lupin that exhibit the traits of high levels of metribuzin tolerance. In this trial the two ‘mutant’ lines (AZ33 and AZ55) demonstrated significantly reduced diflufenican (Brodal®) tolerance, reduced vigour and reduced grain yield (33 to 40%) compared to Mandelup. For these reasons it is unlikely that these new lines will become a commercial reality.

KEY WORDS

Mandelup, metribuzin, mutagenesis, Tanjil AZ33, Tanjil AZ55, herbicide, wild radish

ACKNOWLEDGMENTS

Many thanks to Mingenew/Irwin Group and Bob and Murray Preston for the trial site. Thank you to Dr Ping Si for providing seed of mutant lupin lines. Thank you to GRDC for financial support and to Trevor Bell and Murray Blyth for technical support.

Project No.:	DAW0123
Paper reviewed by:	Wayne Parker

Wild radish herbicides—you get what you pay for

Peter Newman, Department of Agriculture and Food, Western Australia

KEY MESSAGES

Five new wild radish herbicides have come to the Australian market in the past two to three seasons. Two of the new herbicides and one new herbicide mix performed well across twelve herbicide resistance boom sites. Growers now have access to new herbicides that will offer improved wild radish control in cereals. The trick will be to use them wisely to maximise the life span and profit that can be made from the careful implementation of these herbicides into the farming system.

AIMS

To evaluate new wild radish herbicide options in cereals over a range of wild radish populations in the Northern Agricultural Region of WA.

METHOD

Resistance Boom

Nine herbicides were applied to wild radish in wheat crops through a purpose built resistance boom that has the capacity to spray nine different herbicide mixes simultaneously. The resistance boom is comprised of nine small booms, each two metres wide with four nozzles. The resistance boom is a compressed air driven system running at approximately 200 kpa (2 bar) producing a water rate of 70 L/ha through flat fan 0.02 (yellow) nozzles applied at 12 kph. Growers from Yuna in the north to Marchagee in the south were asked to identify sites with ‘hard to kill’ wild radish in cereal crops. The aim was to spray wild radish at the two to four leaf stage, however there was some variation from this ideal weed size. A single replication of each treatment was sprayed in 2 m by 20 to 36 m long strips. Visual ratings of wild radish control (% control compared to un-sprayed strip) were conducted 35 to 42 days after spraying. Surviving wild radish were sprayed out with very high rates of bromoxynil before seed set.

Large scale trial

Eight herbicides were compared on a large scale (80 m x 14 m plots) over wild radish with multiple herbicide resistance. The idea behind the large scale trial was to pick up on low levels of weed survival and to demonstrate the herbicides on a large scale at grower field days. Treatments one to four were applied at the two leaf stage of the wheat crop on 1 July 2008 when the majority of wild radish were at the cotyledon to 2 leaf stage (90% of radish less than 5 cm diameter). Treatments five to eight were applied on 14 July 2008 at the 4 leaf stage of the crop when the majority of wild radish were at the 2 to 6 leaf stage. There were two replicates of each treatment. Treatments were applied in 70 L water/ha through 02 teejet drift guard nozzles at 200 kpa pressure. Weeds were assessed on 13 August 2008 and again on 19 September 2008 by counting surviving weeds in a 0.7 m by 80 m long transect. The ‘old’ formulation of Precept® was used for both the resistance boom and large scale trial (i.e. pyrasulfotole 25 g/L + LVE MCPA 125 g/L)

RESULTS

Precept®, Velocity® and Paragon® + Bromicide200® averaged 98 to 99 per cent wild radish control across the twelve resistance boom sites. Jaguar® and Ecopar® averaged 90 and 92 per cent control respectively.

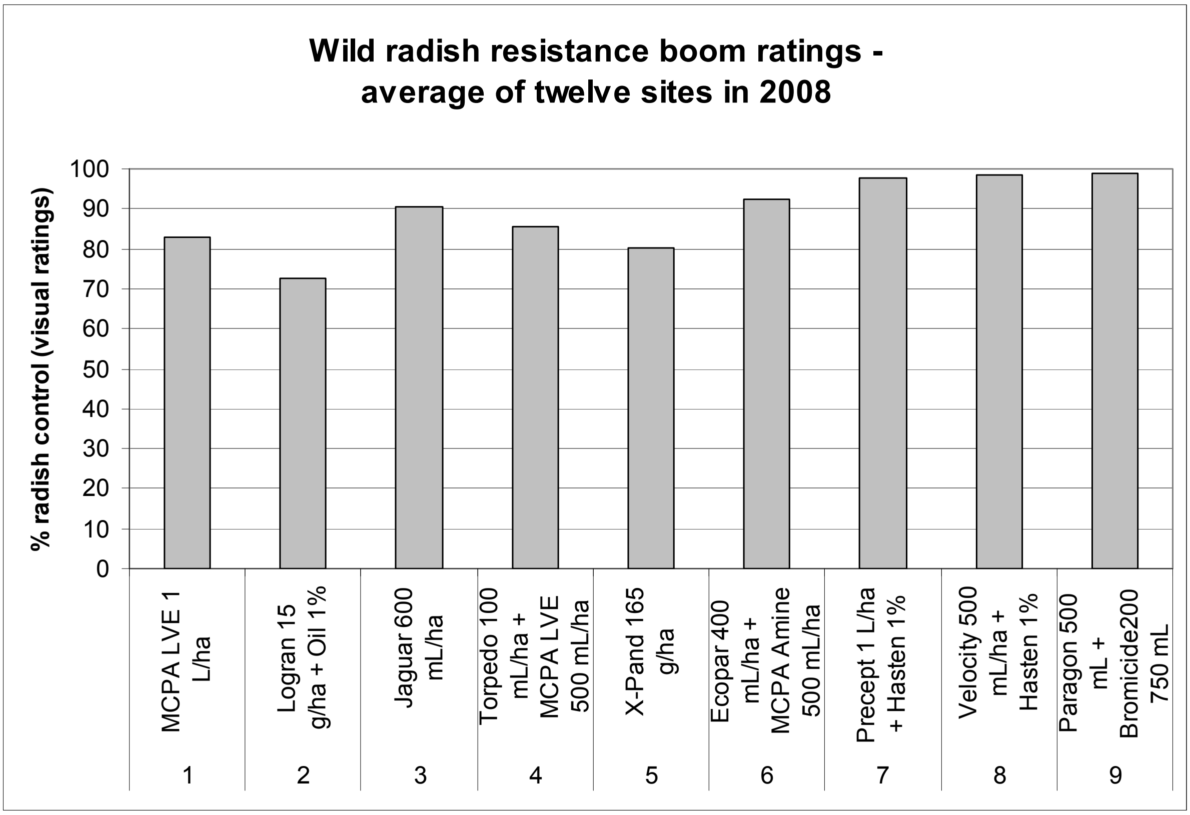

Figure 1 Wild radish control assessed by visual ratings 35 to 42 days after spraying of nine different herbicides/mixes averaged across twelve un-replicated sites in the NAR of WA.

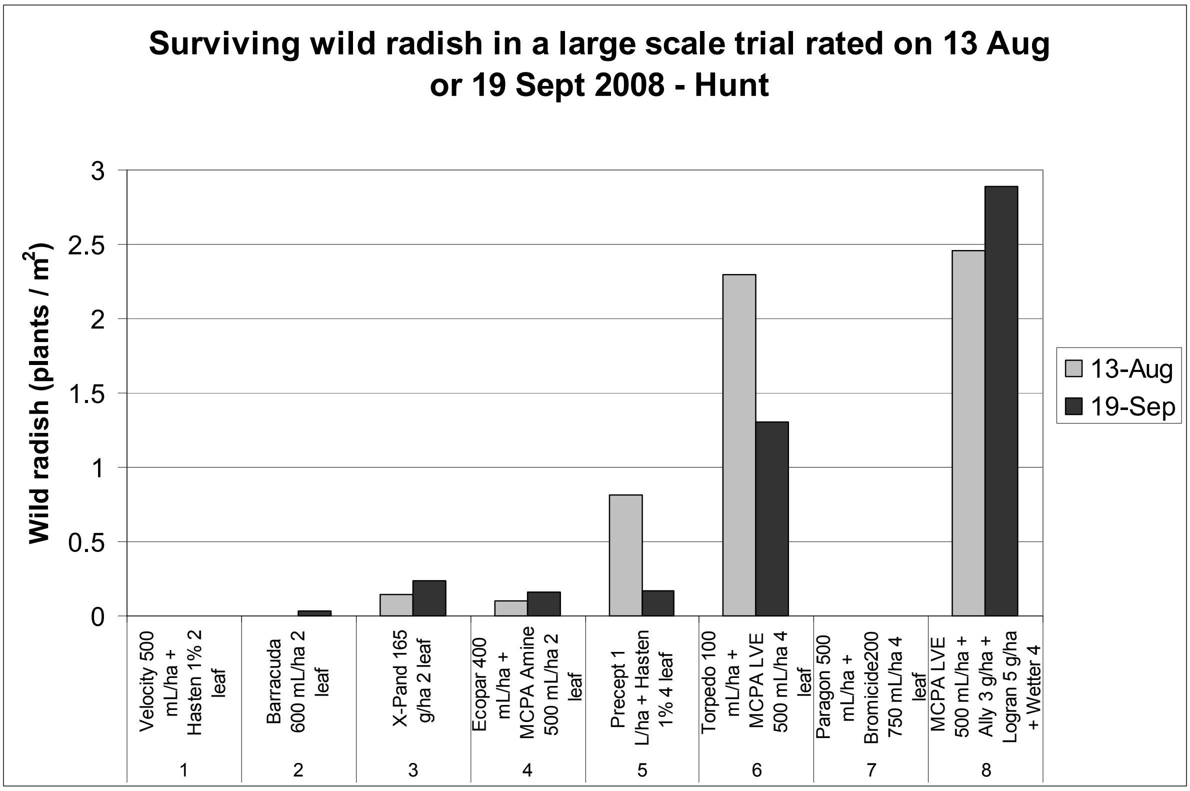

Figure 2 Surviving wild radish (plants/m^2) for a range of herbicides applied on a large scale (14 m x 80 m plots) at Marchagee in 2008.

CONCLUSION

The herbicides Velocity®, Precept® and Paragon® + Bromicide200® were standout performers that gave very reliable weed control at all sites. All of the sites chosen represent hard to kill wild radish and it is encouraging to see that excellent weed control is still possible at these sites in cereal crops. The main barrier to the adoption of these herbicides is the cost. These reliable herbicides/mixes will cost growers $14 to $22 per hectare which is considerably more than they have become accustomed to paying for wild radish control in cereals. The large scale trial was a fantastic demonstration of the old saying ‘you get what you pay for’. The MCPA + Ally + Logran gave predictably poor wild radish control at the large scale trial that presented as a wheat crop full of radish flowers in spring.

Resistance Boom

The resistance boom is an excellent way of demonstrating to growers their resistance status and their options. It demonstrates that a grower should never assume their resistance status. For example, there were four sites where Logran gave 100 per cent wild radish control. Each of these came as a surprise to the grower. There were a number of situations where the grower had assumed that they had group B resistance and it turned out to be phenoxy resistance. Growers will not test every paddock for resistance status. Therefore, if resistance is suspected we should assume that wild radish is resistant to more than one group of herbicides and develop an appropriate herbicide mix. This is where the NuFarm approach of applying three herbicide groups in combination comes into its own. If a particular plant is resistant to one herbicide group then the other two groups should kill it. If a plant is resistant to two herbicide groups then the remaining herbicide should give suppression at the very least. Growers, agronomists and researchers should be working to develop more herbicide mixes using these principles that utilise other herbicide groups.

On average, Jaguar® and Ecopar® also performed well across the twelve resistance boom sites. Ecopar® performed poorly at two sites. Phenoxy resistance was evident at both sites and the weed size was too large for Ecopar® at one of these sites. Ecopar® is likely to be unreliable where phenoxy resistance is prevalent. Jaguar® performed poorly at two sites. The wild radish were too large for this rate of Jaguar® at both sites, hence the poor control. Jaguar® at 600 mL/ha gives reliable control of two leaf wild radish.

Torpedo® and X-Pand® are variable products. At three sites they gave excellent control of wild radish that was resistant to Logran. At another four sites they gave very poor control of Logran resistant wild radish. These products will have little application in the Northern Agricultural Region of WA.

Large scale trial

The benefit of the large scale trial is that it was possible to observe very low levels of wild radish survival when a moderate density of wild radish was sprayed. This trial demonstrated the benefits of early wild radish control. All of the treatments applied at the two leaf stage were much more reliable than those applied at the four leaf stage of the crop. Velocity®, Barracuda® (i.e. Similar to Jaguar®) and Paragon® + Bromoxynil were the standout performers at this site with these plots appearing almost completely clean at harvest time. Precept® had a few survivors. This result is possibly a little un-fair to Precept® as the radish population in one of the plots was much higher than the rest of the site. This is one of the challenges of a large scale trial as the weed population varies over the large site. The two times of weed assessment demonstrate the slow killing time of Precept®.

Wild radish survival of one to two plants per square metre of the Torpedo® and MCPA + Ally + Logran treatments doesn’t sound like much but they looked terrible. These plots presented as a mass of wild radish flowers in spring and would have set an enormous amount of seed.

KEY WORDS

wild radish, herbicide resistance

ACKNOWLEDGMENTS

Thank you to Trevor Bell for technical assistance and to the twelve growers involved.

Project No.: DAW0123

Paper reviewed by: Mike Jackson, NuFarm

Glyphosate—the consequences of cutting rates!

Sally Peltzer and **Dave Minkey**, Department of Agriculture and Food, Western Australia and Western Australian Herbicide Resistance Initiative

KEY MESSAGES

- Use full rates of glyphosate under appropriate environmental conditions.
- Go for maximum control.

DISCUSSION

Glyphosate (a Group M herbicide) inhibits EPSP synthase, an enzyme which is a vital part of the process by which plants make particular amino acids. It is a relatively safe, non-selective herbicide used extensively in the cropping industry. It is an important herbicide but recently producers are tempted to cut rates below label recommendations. The consequences of this may result in greater weed problems in the future due to:

1) Poor control

Cutting herbicide rates reduces the likelihood of optimising weed control under the spraying conditions at hand. Perfect spraying and weed growing conditions are not that common.

It is imperative to spray glyphosate under good environmental conditions as these conditions at the time of spraying influence the effectiveness of the spraying operation. High temperatures, low humidity and windy conditions during spraying may mean a loss of herbicide through drift. Rainfall shortly after spraying may wash the herbicide off the plants before it has had time to act.

Lower levels of control often occur when weeds are under environmental stress when sprayed. For glyphosate to work it must be translocated around the plant to its site of action. The weeds need to be actively growing (not stressed) to maximise the uptake and translocation. Under stressful conditions, such as cold, drought or waterlogging, the transportation and metabolism of the herbicide slows and more herbicide is needed to achieve the highest level of control. Therefore the amount of glyphosate getting to where it works within the plant is the critical factor.

WA research has shown that the environmental conditions over the entire life of the weed affects the performance of glyphosate much more than the conditions on the actual day of spraying.

Rainfall alleviates moisture stress but also washes dust from leaves. This facilitates herbicide absorption, particularly if the rain also raises the humidity of the surrounding air.

Reduced absorption of glyphosate also occurs where weeds have grown in higher air temperatures. These plants have thickened cuticles and more wax on the leaf surface. While rain will reverse the moisture stress it will not reverse the thickening of the cuticle so a higher dose of glyphosate will be required.

Once a weed has been stressed it will always be harder to kill than a weed that has lived an easy life. In these (tougher) situations always keep the rates to the high end of the label recommendation. The best way to avoid such problems is to spray young actively-growing weeds with the recommended label rate.

Recent work by John Moore and Abul Hashem (see article 2009 Crop Update) showed that under most conditions the label rate of glyphosate will provide 95–99 per cent control of annual ryegrass. Under good conditions 50–60 per cent of the label rate usually provides 99 per cent control of annual ryegrass. Lack of moisture and/or nitrogen are the two most common stresses that cause poor control in WA. If the ryegrass is showing signs of yellowing due to nitrogen deficiency or is wilting due to moisture stress then label rates of glyphosate are unlikely to give good control.

2) An increase in glyphosate resistance

In Australia, the intensive use of glyphosate has resulted in resistance appearing in annual ryegrass and there are currently 64 populations of glyphosate-resistant annual ryegrass across Australia. Rate cutting can result in poor weed control and lead to a blow-out in weed numbers. Glyphosate resistance can evolve by selecting survivors of low rates of herbicide application from a susceptible population. Large weed populations have a greater chance of harbouring resistant individuals.

Recent glasshouse experiments from WAHRI suggest that glyphosate resistance can evolve by selecting survivors of low rates of herbicide application from a susceptible population (Busi and Powles, Weed Updates, Agribusiness Crop Updates, Perth WA, 2008, pp. 33–35).

After four cycles of selecting survivors of annual ryegrass when using low rates, control went from 99 per cent to 80 per cent when a full label rate of glyphosate was then used. Similar results were obtained with the same ryegrass population selected with low rates of diclofop-methyl.

So to maintain low weed numbers and avoid this ‘creeping’ resistance, always use robust rates of herbicide. The best way to avoid weed escapes and the development of glyphosate resistance is to strive for maximum control and stop the seed set of weeds that survive a glyphosate application. One successful method is the ‘Double Knock’ which is the use of a second weed control tactic to eliminate the survivors of the first tactic. In WA, the ‘double-knock’ is usually the sequential use of glyphosate followed by paraquat (usually three to 14 days apart).

KEY WORDS

glyphosate resistance, annual ryegrass

Paper reviewed by: John Moore

Reasons to use only the full label herbicide rate

Stephen B Powles, Qin Yu, Mechelle Owen, Roberto Busi and **Sudheesh Manalil**, WA Herbicide Resistance Initiative, School of Plant Biology, University of Western Australia

KEY MESSAGE

Use herbicides at full label rates and do not cut herbicide rates as this can contribute to herbicide resistance evolution.

AIMS

1. Increase awareness that rate-cutting to below label herbicide rates may contribute to herbicide resistance evolution.
2. Understand how the Group A herbicide clethodim remains effective on otherwise herbicide resistant ryegrass and the effect of herbicide rate on clethodim and other herbicide sustainability.

BACKGROUND

New, unique herbicides for use in world agriculture are developed and commercialised by a handful of major international corporations working in a competitive, technologically intensive industry. All herbicides must satisfy very stringent regulatory evaluation before they are commercialised. In Australia the regulator is the Australian Pesticides and Veterinary Medicines Authority (APVMA). Amongst a great deal of information that must be supplied to the APVMA is the extensive field data supporting the recommended commercial label rate at which the herbicide should be used in Australia. The APVMA evaluates this data as part of the registration process and confirms the legal herbicide label rate (grams/hectare). The herbicide should only be used at the registered label rate.

It is important to recognise that by world standards the label rates of herbicides used in Australia are nearly always considerably less than that used in other comparable parts of the world. For example, the label rates of most herbicides registered for the control of annual ryegrass in Australia are about half of that registered for the control of ryegrass in other parts of the world, including the USA, Canada and Europe. The principal reason for this difference is economic in that herbicides in Australia must be modestly priced because Australia has low crop yields, very large farms and no crop subsidies. The result is that herbicide label rates in Australia are often half of that prevailing in comparable other nations.

Notwithstanding the low herbicide label rates (grams/ha) in Australia there has been and sometimes continues to be a culture of rate cutting below the label rate. Thus, despite the already low rates by world standards, herbicides are sometimes used at below the label rate. The adverse biological consequences of such low herbicide use rates in Australia is that there can be substantial weed survivors and herbicide resistance risks can be exacerbated, especially in cross pollinated weeds like annual ryegrass. Recent WAHRI research has shown that recurrent selection of herbicide susceptible ryegrass at low, below-label rates of diclofop-methyl can result in the rapid evolution of herbicide resistant ryegrass (Neve and Powles 2005 a,b). Similarly, recurrent selection of glyphosate susceptible ryegrass at low, below-label rates of glyphosate resulted in a shift towards glyphosate resistance (Busi and Powles, unpublished). Now, we also have data showing the importance of using full label rates for maintaining the sustainability of clethodim.

RESULTS

Our research to understand the mechanistic basis of resistance to Group A herbicides in ryegrass, and the work of others, has revealed that resistance can be endowed by various mutations of the ACCase gene and/or due to enhanced rates of herbicide metabolism. We have identified (Zhang and Powles 2006a,b, Yu et al. 2007) in ryegrass populations that different mutations of the ACCase gene can endow target site resistance to ACCase herbicides (Table 1). It is important to note that as ryegrass is a cross-pollinated species that individual plants can have more than one of these mutations and that individuals can be heterozygous or homozygous for mutations. This information has enabled us to be further convinced of the importance of using herbicides at the full label rate.

Table 1 **Mutations of the ACCase gene endowing herbicide resistance**

Amino acid #	Amino acid substitution	Resistance
1781	Isoleucine to Leucine	Fops & Dims
1999	Tryptophan to Cysteine	Fenoxaprop only
2027	Tryptophan to Cysteine	Fops & Dims
2041	Isoleucine to Asparagine	Fops & Dims
2078	Asparagine to Glycine	Fops & Dims
2088	Cysteine to Arginine	Fops & Dims
2096	Glycine to Alanine	Fops only

We have established that ryegrass resistance across many ACCase herbicides is very widespread in WA (Llewellyn and Powles 2001, Owen et al. 2007). However, our surveys and the experience of agronomists and farmers show that the ACCase herbicide clethodim continues to be effective on many otherwise ACCase herbicide resistant ryegrass. WA farmers often rely on clethodim to control ryegrass and some other grass weeds in dicot crops. The obvious question is why clethodim continues to be effective on ryegrass when ryegrass has such widespread resistance to other ACCase herbicides. We now know that clethodim continues to work for several reasons:

1. Clethodim is not metabolised by plants and therefore enhanced metabolism is not available as a resistance mechanism in ryegrass. Similarly, wheat cannot metabolise clethodim.
2. Some ACCase resistance mutations do not endow clethodim resistance if clethodim is used at the label rate. At label rate usage the 1999 mutation and the 2096 mutation (Table 1) do not endow resistance to dim ACCase herbicides such as clethodim.
3. If clethodim is used at the label rate then resistant ryegrass endowed by one copy of the 1781 mutation (heterozygous state) is killed by clethodim. This is an important finding because in WA the 1781 mutation is the most common ACCase resistance mutation and ryegrass plants are often heterozygous for this mutation. Therefore heterozygous individuals carrying this mutation are resistant to label rates of several ACCase herbicides but remain susceptible to clethodim IF clethodim is used at the label rate. Obviously, if the rate of clethodim is below the label rate then heterozygous individuals with the 1781 mutation can survive. Resistance to clethodim at the label rate is manifest if a ryegrass plant has two copies of the 1781 mutation (homozygous).
4. The 2078 and 2088 ACCase gene mutations DO endow clethodim resistance at the label rate of clethodim. However, these two mutations are relatively weak mutations and treated plants are damaged by the label rate of clethodim. Additionally, and importantly, these mutations result in a fitness penalty for the plant. The implications of the fitness penalty is that plants with these mutations do not grow as well and are not as competitive as normal ryegrass. Therefore, individuals carrying either of these mutations are not as competitive as normal ryegrass and clethodim at the label rate strongly inhibits their growth (but does not kill them). The combined effect of a weak mutation and a fitness penalty is that clethodim at the label rate strongly inhibits the growth of resistant individuals with these mutations. For ryegrass plants with the 2078 or 2088 ACCase gene mutations clethodim at the label rate strongly inhibits their growth, giving the unaffected growing crop the chance to further suppress their growth.

CONCLUSIONS

The evidence we have accumulated from our studies of the genetic and biochemical basis of herbicide resistance in ryegrass and other resistant weed species leads us to the conclusion that herbicides should be used at the registered, legal label rate. Do not cut the rate below the label rate. Our molecular genetic work explains why clethodim continues to work on some otherwise ACCase herbicide resistant populations and the message remains the same that rates should be kept high. We hope that crop agronomist/consultants will join with us in advocating that the best way to use a herbicide is to use it ONLY at the label rate and to rotate the herbicide with herbicides of different mode of action and with any possible non herbicide tools for weed control. In this manner, herbicides will have a longer life and therefore be more sustainable in Australian agriculture.

KEY WORDS

herbicide resistance, ACCase, mutations, clethodim, cut rates

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Project No.: GRDC UWA 00112

Paper reviewed by: David Minkey

Mandelup has reasonable tolerance to atrazine

Leigh Smith and **Peter White**, Department of Agriculture and Food, South Perth

BACKGROUND

During the early years of Mandelup's release, some farmers reported that its emergence was poor, plant density was low and seedlings showed symptoms like simazine toxicity (White and Shea 2006). Trial results showed Mandelup was as tolerant or more tolerant of simazine then other lupin varieties. During the early parts of the 2008 growing season some farmers commented that Mandelup was more sensitive to atrazine than other lupin varieties. These observations were based on the amount of damage seen in Mandelup after atrazine application compared with their experience with other varieties.

In 2006/07, we developed a simple protocol using plants grown in pots in the glasshouse to give an indication of the susceptibility or tolerance of lupins to soil applied herbicides (White and Smith 2007). This protocol was used to provide a simple and quick assessment of Mandelup's tolerance to atrazine compared with other lupin varieties.

AIM

Determine the relative tolerance of Mandelup to atrazine.

METHOD

Treatments consisted of 5 atrazine rates (0.0, 0.1, 0.2, 0.3, 0.4 µg atrazine/g soil), 7 narrow leaf varieties (see Table 1) with three replications, arranged in a randomized complete block design. Pots contained 2.75 kg of red sandy loam soil and were sealed at the bottom to prevent drainage. Full basal nutrients (except N) were applied in solution to the soil surface of each pot. Atrazine also was applied as a suspension to the soil surface. After the nutrients and atrazine had dried they were thoroughly mixed through the soil. Ten seeds per pot were sown and each seed was inoculated with Group G peat-based inoculum. The water content of pots was maintained at field capacity by regularly watering to weight.

Plant numbers were counted 9 days after seeding (DAS) and each pot was thinned to 5 plants/pot.

Plants were scored for the severity of scorching on leaves at 16, 18 and 21 days after seeding (DAS). Plants were rated on the severity of leaf scorch with no symptoms = 0, to severe or plant death = 5. At 21 DAS plant shoots were harvested to determine the dry matter production between the different rates of atrazine and varieties.

RESULTS

Leaf Scorch

The atrazine application had no effect on the emergence of plants. The first signs of symptoms appeared 16 DAS, when 0.2 µg atrazine/g soil or higher was applied. Danja and Coromup showed the most severe symptoms of atrazine damage.

By 21 DAS the severity of leaf scorching increased ($p = 0.001$) as the rate of atrazine increased (Table 1).

Table 1 **Leaf scorching 21 days after sowing in response to atrazine application. Plants scored on a 0 to 5 scale. 0 = no symptoms; 5 = dead plants**

Variety	**Rate of Atrazine application (µg atrazine/g soil)**				
	0	**0.1**	**0.2**	**0.3**	**0.4**
Coromup	0	1.2	3.8	4.5	5.0
Danja	0	0.7	3.8	5.0	5.0
Gungurru	0	0.7	3.2	4.2	4.8
Jenabillup	0	0.2	2.5	3.3	4.2
Kalya	0	0.5	1.0	3.2	4.0
Mandelup	0	0.5	2.2	3.7	3.5
Tanjil	0	1.0	3.3	4.3	4.5

At the 0.2 µg rate Kalya, a reasonable tolerant line to atrazine had 74% lower score for leaf scorch than Danja, a known sensitive line. Mandelup had 43% less leaf scorch than Danja. At the highest rate of atrazine, Kalya and Mandelup had 20% and 30% less leaf scorch than Danja, respectively.

Dry Matter Production

The application of atrazine reduced the dry matter production of all varieties ($p < 0.001$), with the effect of atrazine rates within varieties was varied but also significant ($p < 0.001$, 5% l.s.d. = 0.0924). With the presences of atrazine, Mandelup had the least dry matter production loss 46% from zero chemical to the highest rate of chemical applied. The dry matter production of Danja was reduced the most by atrazine (67%) and Gungurru and Kalya had a loss of 60% and 53% respectively (Figure 1).

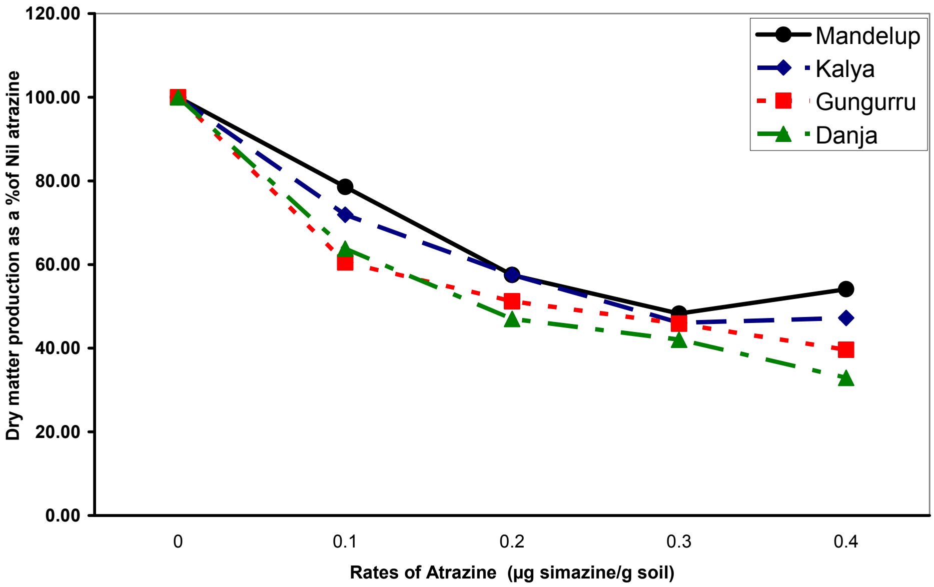

Figure 1 **Dry matter production of shoot weights as a proportion of the maximum dry weight in response to atrazine application.**

For the simplicity of the Figure 1, only 4 varieties have been shown. The responses of the other varieties to atrazine were all within the extremes of Mandelup and Danja. Tanjil and Jenabillup were similar to Kalya and Coromup was between Gungurru and Danja at the highest rate of atrazine applied.

Although the data isn't shown in this article, there was an additional treatment of a single rate of simazine (0.2 µg simazine/g soil) by the 5 rates of atrazine was applied to an extra Mandelup. With this treatment, Mandelup's biomass was reduced by 31% from nil to the highest rate of atrazine. Comparing this treatment to nil atrazine and nil simazine, Mandelup had a decrease in plant biomass production of between 38% and 57%. From the 0.2 µg atrazine and higher, Mandelup plus simazine had a plant biomass production loss similar to Kalya and Gungurru.

CONCLUSION

These results suggest that Mandelup is as tolerant or more tolerant to atrazine than other lupin varieties. It also confirmed other research (White and Smith 2007) that when other triazine based chemicals are applied, Mandelup has tolerance.

There are a range of environmental and soil factors that affect tolerance to atrazine in lupins. For example, damage caused by high rates of atrazine may often be more severe is in warm, wet seasons (producing lupins 2008). We don't know if these factors affect Mandelup's tolerance to atrazine more than other varieties.

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