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Crop Updates 2007 - Weeds

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Acknowledgements

2007 CROP UPDATES – WEED UPDATE

This years Weed Update is packed with information despite the challenging growing conditions experienced in 2006.

There is a focus on wild radish, a perennial weed problem, with some insights on seedbank management and combating resistant populations. Also there are some very informative papers on glyphosate resistance in annual ryegrass (a very serious threat to our current cropping systems) and gene flow via pollen between ryegrass populations.

There are numerous papers concerned with herbicides, alternatives to trifluralin, new herbicides and new ways to use our older chemistry, as well as herbicide tolerance of new cereal varieties.

I would like to thank all of the authors (for submitting papers on time and in the correct format (for the most part anyway)), reviewers (for giving up their time and expertise to make this a better publication) and other convenors for their contribution to getting this book compiled and completed on time.

A special thanks to Chiquita Butler in Document Support (and any of the others who may have leant a hand) and to Julie Roche and Carol Llewellyn for emphasising the urgency of deadlines.

Alexandra Douglas
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Decimate a wild radish seed bank in five years

Peter Newman, Sally Peltzer, Abul Hashem and Aik Cheam, Department of Agriculture and Food, Western Australia

KEY MESSAGES

Five trials across Western Australia have demonstrated that it is possible to erode a wild radish seed bank by 95% over four to five years of complete (100%) or near complete seed set control. This equates to approximately 50% seed bank decline each year.

Leaving wild radish seeds at or near the soil surface will minimise seed dormancy and maximise pod decay and seed predation by ants.

Including shallow cultivation each year will maximise disruption of the protective pod which leads to decreased dormancy and increased germination.

Some very big seed banks of wild radish may take six to seven years to erode to acceptable levels.

AIMS

To demonstrate the most effective way to decimate a wild radish seed bank to a point where a paddock may return to a phase of cropping with low wild radish density.

METHOD

Mullewa, Wongan Hills and Mt Barker

These trials were designed purely to measure seed bank decline of a number of weeds through time, with and without tillage. This involved counting emergence of weeds followed by spraying with Spray.Seed® to ensure complete kill. Three to four cohorts of weeds were counted each year. A cultivation treatment was conducted on the same plots each year using two passes with a cone seeder fitted with knife points. These sites were natural populations of wild radish. The Mullewa populations were old seed banks where wild radish had been allowed to set seed for a number of years prior to the trial. The Mt Barker and Wongan populations experienced a one-off blow out of wild radish in the year prior to commencing the trial.

Mingenew and Merredin

The Merredin site was an introduced seed bank of approximately 350 seeds/m². The Mingeneu site was a natural seed bank with a starting seed bank of approximately 5000 seeds/m². These sites were rotation trials that looked at a range of rotations, chemical and non-chemical weed control options to manage a wild radish population. The data featured in this paper are from plots where 100% wild radish control was achieved each year by hand-weeding at the Merredin site but at the Mingeneu site only two years had complete seed set control while the remaining three had near complete seed set control using existing tactics currently available to farmers. Each site was cultivated with no-till seeding equipment each year.

RESULTS

Mt Barker and Wongan Hills

Much of the wild radish seed was dormant in the first year of the trial due to the age of the seed. Cultivation in the second year of the trial led to a flush of wild radish germination (Figures 1 and 2). In other trials where the wild radish seed bank was an old seed bank there was no significant response to cultivation in year two (data not shown).

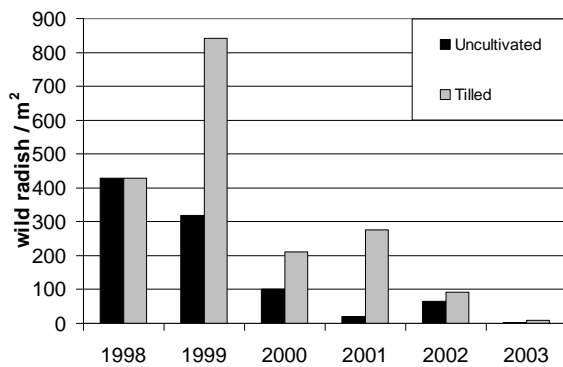


Figure 1. Wild radish germination at Mt Barker with and without cultivation over five years.

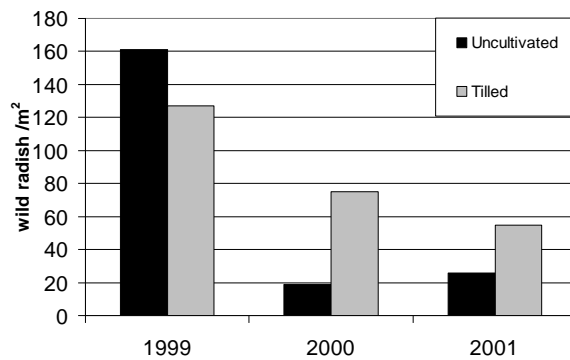


Figure 2. Wild radish germination at Wongan Hills with and without cultivation over three years.

Average of five seed bank trials

Over five trials the wild radish seed bank was eroded by 94% over four years and by 98% over five years of total seed set control (Figure 4).

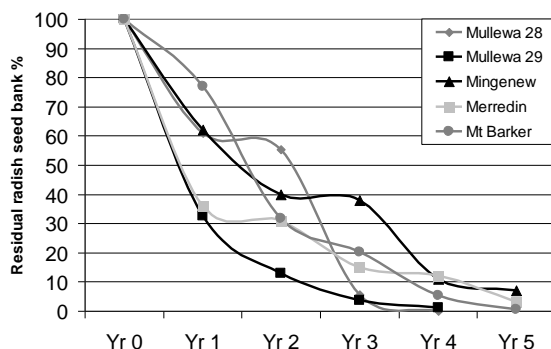


Figure 3. Residual wild radish seed bank (%) at five trial sites with cultivation and no seed set over five years.

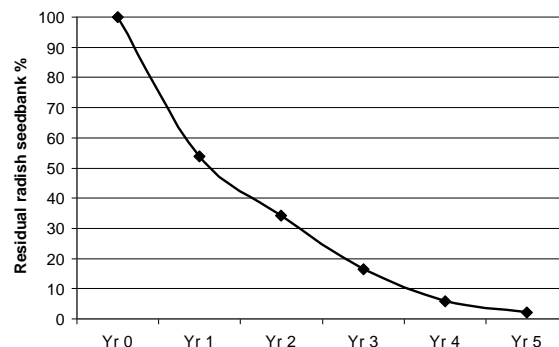


Figure 4. Residual wild radish seed bank (%) average of five trials with cultivation and no seed set over five years.

CONCLUSION

How long to erode a wild radish seed bank?

The long term seed bank trials show that it is possible to erode a wild radish seed bank by 96% (on average) with four years of complete weed control. This equates to approximately 50% decline of the seed bank each year. This agrees with previous research by Code *et al.* (1987) where only 3% of wild radish that was buried at 1 cm depth was viable after four years. Looking at the individual trial data, the wild radish seed bank was eroded by at least 93% (i.e. Mingenew site) over five years. However, the starting seed bank at Mingenew was 5000 seeds/m² so at the end of five years there were still 350 seeds/m² in the seed bank. This, coincidentally, was the starting point for the Merredin trial. So it can be misleading to look at percentages alone. The big question is, how low a wild radish seed bank should be prior to returning to a phase of cropping.

Cultivation

Each of these trials included some cultivation with no-till (knife point) seeding equipment each year. Cultivation can do several things to wild radish seed.

- Cultivation can redistribute weed seeds to varying depths in the soil depending on the implement. Shallow cultivation can place seeds in the top 2 cm of soil, ideal for germination. Deep cultivation can place seeds deep in the soil from where they cannot emerge.

- Cultivation causes physical damage to the seed pod which reduces the dormancy of the seed. The wild radish pod enforces dormancy on the seed by slowing uptake of water, protecting the seed coat and alkaloids within the pod reduce bacterial decay of the pod and seed. Physical destruction of this pod through tillage reduces the dormancy of wild radish.
- Cultivation moves seed from light to dark and vice versa. Wild radish germination is enhanced if it is vernalised in the light and then shallow buried (Piggins *et al.* 1978). The fact that buried seeds need exposure to light and surface seeds prefer darkness for germination partially explains the germination stimulation by cultivation.

The flush of wild radish germination seen in the second year of the Mt Barker and Wongan Hills trials is likely to be due to the wild radish being in a dormant state in year one of the trial. The radish was dormant in year one due to the majority of seed being only one year old, and hence the pod would have been in tact. As the wild radish pod aged, the cultivation led to more destruction of the protective pod and placed seed at the ideal depth for germination.

Depth of burial

Several studies in the past (Reeves *et al.* 1981; Code *et al.* 1987) have demonstrated that burial of wild radish seed to a depth of 10 cm increases the seed longevity compared to seed at the surface to 2 cm depth. In one study, 43% of wild radish seed was viable after four years of burial at 10 cm. This compares to 3% viability of seeds that were buried for four years at 1 cm depth. So the message is simple. Aim to keep wild radish seed in the top 2 cm of soil to maximise decay and maximise the rate at which a seed bank can be eroded. Should a paddock be deep cultivated (e.g. with a mouldboard plough) it is important to leave these seeds at depth for up to 10 years to allow maximum decay.

Predation

Ants are responsible for the vast majority of seed predation in Australia (Minkey *et al.* 2006). Birds and rodents do also predate some seeds but this is insignificant compared to ants and is often restricted to the edges of the paddock. Ants predate seeds from the soil surface only. Seeds that are covered with even just a few millimetres of soil are difficult for ants to predate. Seed decay is difficult to measure and is therefore poorly understood. However, seed decay through a variety of means can account for up to 50% of removal of seeds from the seed bank. Wild radish seeds should be left on the soil surface to maximise decay through predation and other means.

What is an acceptable seed bank?

Earlier research (Hashem *et al.* 2006) on the competition between wild radish and lupin showed that competition from even 3 radish plants/m² in the lupin crop could reduce lupin grain yield by 16 to 24% mainly by reducing photosynthetically active radiation on lupin canopy by 48%. Thus it appears that even a low seed bank of wild radish (< 10 seeds/m²) may pose a high risk to crops if control failure occurs. Furthermore, the fecundity of wild radish plants at this low density is generally very high and therefore they must not be allowed to set seed. It is not possible to define a specific wild radish seed bank threshold as this will vary depending on resistance status, farming system and location. It is unlikely that wild radish would ever be eradicated from WA farms. An acceptable seedbank should be viewed as one that is not growing and is having minimal impact on crop yield.

KEY WORDS

wild radish, seed bank life, cultivation, predation

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Paper reviewed by: Sally Peltzer, Abul Hashem and Aik Cheam

High level of seed-set control in wild radish is achievable

Aik Cheam and Siew Lee, Department of Agriculture and Food, Western Australia, South Perth

KEY MESSAGES

- A high level of seed-set control in wild radish has been achieved by matching the stage of development in wild radish seed with the growth stage of the lupin crop.
- Triasulfuron applied at the post-embryo stage of wild radish and at 80% leaf drop of lupin gave up to 97% seed set reduction in wild radish.
- Metosulam, on its own or in combination with diflufenican or picolinafen, as a selective spray topping treatment on pre-embryo wild radish in lupin resulted in up to 98% seed set control.

AIM

To demonstrate that effective seed-set control of wild radish is achievable.

INTRODUCTION

The ability to control seed-set of wild radish has been a challenge to researchers and farmers alike for many years. In the past, many had relied on the various tactics that have successfully controlled the seed-set of other weeds, particularly annual ryegrass. However, the results obtained were far from satisfactory. Hence, it was rationalised that a better understanding of the embryo development in wild radish seed in relation to the timing and type of control measures could be the key to improving seed-set control. With this in mind, a series of studies were conducted.

METHOD

Initially, under a non-cropped environment, wild radish plants of different growth stages growing in the field were used to determine their viable seed production following mechanical slashing. The presence or absence of embryo in the developing seed was used as the criterion for determining the different growth stages. Stages 1 and 2 are the pre-embryo stages where stage 1 refers to early flowering and pod development with newly-formed thin pods. Stage 2 refers to mid-flowering and pod fill when pods of wild radish are still green, squashy and watery but seed development is at ovule stage without embryo. Stages 3 and 4 are post-embryo stages when the presence of embryo is clearly visible but the pods of stage 3 are still squashy and watery in contrast to the woody pods of stage 4.

In subsequent trials, a number of contact and translocated herbicides were used to target the pre- and post-embryo stages to determine their efficacy on seed-set control of wild radish and their safety on crops, in particular lupins for which there are limited selective herbicides for controlling wild radish.

RESULTS

Pre-embryo target

At the pre-embryo stages of wild radish development, up to 100% seed-set control was achieved through slashing (Table 1).

Table 1. Impact of slashing on seed production of wild radish

Wild radish growth stage	Viable seed production (%)	
	Site 1	Site 2
1	0	0
2	4.9	4.0
3	63.3	75.1
4	92.5	89.1

Although the most critical stage to control seed-set is before the formation of embryo in the developing wild radish seed, damage to crops is inevitable if a desiccant herbicide such as paraquat or glyphosate is applied as a crop topping treatment at this stage (Table 2).

Table 2. Proportion of viable seed reduction (%) of wild radish per plant compared with untreated control in lupins following crop topping of lupins at various maturity stages. In brackets are percent yield loss of lupins compared with untreated control

Treatment	Lupin (L) and wild radish (WR) stages at spraying time			
	No. leaf drop (L) Stage 1 (WR)	50% leaf drop (L) Stage 3 (WR)	80% leaf drop (L) Stages 3 & 4 (WR)	100% leaf drop (L) Stage 4 (WR)
Gramoxone® 800 mL	100 (65)	64 (7)	63 (4)	40 (0)
Gramoxone® 4 L	100 (92)	81 (14)	84 (9)	42 (2)
Roundup CT® 1 L	100 (100)	90 (15)	85 (12)	52 (1)
Roundup CT® 5 L	100 (100)	97 (19)	85 (9)	77 (8)

Lupin yield losses ranged from 65 to 100%, depending on the desiccant and its concentration, but all treatments gave complete control of wild radish seed-set.

At 80% lupin leaf drop, the timing currently recommended for the seed-set control of annual ryegrass, only 63% reduction of viable wild radish seeds were obtained following crop topping with Gramoxone® at 800 mL/ha. The wild radish plants were already at stages 3 and 4 at the time of spraying. In contrast, Roundup CT® being a translocated herbicide was more effective when sprayed at 1.0 L/ha resulting in 85% viable seed reduction but there was greater crop damage. At 100% lupin leaf drop, no yield loss was recorded following 800 mL/ha Gramoxone® but there was 1.0% loss following 1.0 L/ha Roundup CT® and the viable seed reduction of wild radish was only 40 and 52 per cent, respectively.

Subsequent trials targeting the pre-embryo stages, confirmed that Eclipse® on its own or in combination with Brodal Options® or Sniper® were effective on seed set control of wild radish with no damage to the lupin crop when applied as a selective spray topping treatment immediately after crop flowering. Up to 98% seed set reduction of wild radish were recorded when treatments were on a population susceptible to Eclipse® (Table 3).

However, Eclipse® had no effect when applied on a population resistant to Eclipse®, but partial seed set control ranging from 39 to 69% was obtained when Eclipse® was mixed with a Group F herbicide such as Brodal Options®, Sniper® or Balance® to which the population was still susceptible (Table 3). Some damage to the harvested lupin seed in terms of loss of seedling vigour in some of the treatments was noted. This could be the consequence of waterlogging in 2005.

Table 3. Wild radish viable seed reduction per plant as per cent of control following selective spray topping lupin in 2004 and 2005. Lupin yield, germination and seedling length were also expressed as per cent of control

Treatment	Wild radish viable seed reduction		Lupin ^c				
			Yield	Germination		Seedling length	
	2004 ^a	2005 ^b	2005	2004	2005	2004	2005 ^d
Eclipse® 10 g	97.5	0.0	117.6	128.9	100.0	123.6	79.6
Eclipse® 10 g + Brodal Options® 100 mL	88.2	68.7	115.7	121.1	100.0	111.9	108.0
Eclipse® 10 g + Sniper® 33 g	88.0	38.6	128.7	110.5	100.0	100.0	86.2
Balance® 100 g	72.1	65.5	102.8	119.3	100.0	111.1	85.0
Eclipse® 10 g + Balance® 50 g	-	45.9	73.1	-	100.0	-	105.1
No herbicide control	0.0	0.0	100	100	100.0	100.0	100.0
			(1.08 t/ha)				

^a 2004 wild radish was susceptible to Eclipse®.

^b 2005 wild radish was resistant to Eclipse®.

^c 2004 lupin variety was Belara and 2005 variety was Mandelup.

^d There was water-logging in 2005, due to heavy rain.

Post-embryo target

The most effective post-embryo herbicide screened to date in the programme was Logran®. It gave up to 97% seed set control with no impact on lupin yield but there could be a slight loss in germination and seedling vigour (Table 4).

Table 4. Viable seed reduction of wild radish per plant and lupin yield, germination and vigour expressed as per cent of control following crop topping lupin in 2004 and 2005

Treatment	Wild radish ^a viable seed reduction		Lupin ^b				
			Yield	Germination		Seedling length	
	2004	2005	2005	2004	2005	2004	2005
Logran® 15 g + oil 1.0%	96.9	93.9	126.4	95.8	98.7	89.0	82.6
Glean® 10 g + MCPA amine 1 L	89.3	-	-	95.8	-	23.6	
Reglone® 2 L	88.0	61.3	88.2	81.3	100.0	91.2	
Logran® 10 g + MCPA amine 1 L	86.2	-	-	89.6	-	59.1	
Hammer® 75 mL + MCPA amine 0.5 L	85.6	-	-	100.0	-	48.6	
Eclipse® 5 g + MCPA amine 1 L	80.6	-	-	50.0	-	21.3	
Logran® 10 g + oil 1.0%	79.0	83.9	115.2	102.1	100.0	121.7	88.5
Gramoxone® 400 mL + MCPA amine 1 L	71.9	67.8	110.7	95.8	100.0	92.3	34.7
Broadstrike® 25 g + MCPA amine 0.5 L	71.3	89.6	129.2	102.1	100.0	84.1	65.2
Broadstrike® 25 g + oil 0.5%	70.5	70.6	107.9	95.8	100.0	112.7	98.1
No herbicide control	0.0	0.0	100.0	100.0	100.0	100.0	100.0

^a 2004 wild radish was susceptible to Eclipse® but 2005 wild radish was resistant.

^b 2004 lupin variety was Belara and 2005 variety was Mandelup.

When Glean®, Logran®, Hammer® or Eclipse® was mixed with the phenoxy MCPA amine, more than 80% seed-set control was achieved but there was a severe reduction in the lupin seedling vigour (Table 4). The rest of the herbicides tested were less effective, resulting in seed set control from 70 to 79%.

Interestingly, Logran® also gave very effective seed set control of an Eclipse®-resistant wild radish population tested in 2005. This is despite that both Eclipse® and Logran® are ALS inhibitors. This could be explained by the fact that resistance to ALS inhibitors can be endowed by several different mutations of the ALS gene, consequently there are various patterns of resistance across Group B

herbicides. Some mutations allow some Group B herbicides to be effective while other mutations result in resistance to all Group B herbicides. Herbicide resistance testing of a wild radish population for cross resistance to the various Group B herbicides is therefore essential.

CONCLUSION

Crop topping with a non-selective herbicide like paraquat at 80% leaf drop in lupin resulted in seed set reduction in wild radish not exceeding 65%. However, the ALS-inhibitors, triasulfuron and metosulam showed great potential for late and early crop topping of lupins respectively, resulting in up to 98% reduction in numbers of viable wild radish seeds with little to no effect on crop yield.

KEY WORDS

wild radish, seed-set control.

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Paper reviewed by: J.R. Peirce

Wild radish: Best management practice

Aik Cheam and Siew Lee, Department of Agriculture and Food, Western Australia, South Perth

KEY MESSAGES

- As wild radish germinates throughout the year and over many seasons, effective management requires a thorough and persistent weed control program for several seasons to minimise fresh seed input and to rundown the existing seedbank.
- As with all weed management, the integration of chemical and non-chemical methods is paramount to obtain acceptable control of wild radish and help reduce the risk of resistance.
- Although up to 98% of the seedbank could be depleted over five years, the size of the seedbank at the start of the management program will determine whether the remaining seeds will impact on future crops.

INTRODUCTION

The need to manage wild radish effectively is more critical today than ever before because wild radish numbers and resistance to herbicides are on the increase. Herbicide resistance is a relatively new problem, but achieving long-term control of wild radish has always been a challenge. The rapid development of herbicide resistance is caused by our over-reliance on herbicides exacerbated by the weed's ability to transfer genes rapidly through cross-pollination because wild radish is an outcrossing species. As for our inability to achieve long term control of wild radish we can attribute this to crop-related factors and the unique biology of the weed which includes its abundant seed production, complex seed dormancy, germination flexibility, seed longevity and high competitive ability.

This paper addresses the question: "What is the best management practice against wild radish?" Although there is no one plan that fits all paddocks and circumstances, one must know what management tools to use or to avoid. To achieve this, one must have a good understanding of the weed. Understanding how chemicals and other tools can be used in a planned program to progressively reduce the recurrence of the weed on the farm is imperative. Fortunately, with the availability of many effective control measures against wild radish, there is hope that wild radish can be effectively managed. This optimism is supported by our good understanding of the weed and its responses to most of the individual control techniques. In fact, wild radish is one of the most intensively-studied weeds in this country.

KNOW YOUR WILD RADISH HERBICIDE RESISTANCE STATUS

Knowing the herbicide resistance status of your wild radish in the farm is of the highest priority before the commencement of any management program. This is to ensure effective and economical future management decisions. The wild radish population should be tested for herbicide resistance if you are not sure of its resistance status. In this country, wild radish populations are now known with resistance to four herbicide Groups, Groups B, C, F and I. Group B resistance is the most common, followed by Group F, Group I and Group C in that order (Table 1).

Table 1. Status of resistance of wild radish in Australia (Modified: Original source C. Preston)

Herbicide Group	Herbicide example	States with confirmed resistant populations					
		WA	SA	VIC	NSW	TAS	QLD
B – sulfonyl ureas	chlorsulfuron	X	X				
B – sulfonamides	metosulam	X	X				
B – imidazolinones	imazapic, imazapyr	X	X				
C – triazines	simazine, atrazine	X					
F – nicotinanalides	diflufenican	X					
I – phenoxies	2,4-D	X					
B + C + F		X					
B + F + I		X					
C + F + I		X					

It is common to find populations that have developed multiple resistance across several modes-of-action. Resistance to herbicides in up to three mode-of-action groups has been documented in individual populations. However, individual populations resistant to four mode-of-action groups have yet to be found and it won't be long before we do.

MANAGING HERBICIDES

Although Western Australia is leading Australia and the rest of the world in herbicide resistance, there are populations in Western Australia that are still susceptible to all four herbicide groups. Steps can be taken to delay herbicide resistance by using strategic rotations of herbicide groups. Where possible, reduce reliance on a high risk group such as Group B. The low cost and efficacy of Group B herbicides have resulted in their over use, where multiple applications have been common in the same season. Groups C and F have been considered of moderate risk while Group I of low risk. But the extent to which herbicide groups can be used will be largely determined by what we can use in alternate phases of the rotation.

General guidelines for use of the various herbicide groups in winter cropping systems are well-documented in various publications. Suffice to say that where a Group B herbicide has been used pre-emergence or early post-emergence in cereals, avoid clean up sprays of Logran®. Use a phenoxy to clean up before booting stage of the crop. It is also good practice to use mixtures containing different herbicide groups, such as diflufenican + MCPA (Tigrex®) or diflufenican + bromoxynil (Jaguar®). The use of Eclipse® on flowering wild radish in lupins following cereals previously treated with a Group B herbicide should also be avoided, according to the guidelines. The guidelines also stipulate that no Group C herbicides are to be applied in consecutive years. Hence, in the lupin/wheat rotation, where simazine or atrazine are used in lupins, it follows that no diuron, bromoxynil or terbutryn is to be used in the cereal. Similarly, if diflufenican is used in lupins, no Tigrex® or Jaguar® is to be used in cereal.

These guidelines although useful in the general sense, appear to be over cautious by assuming that there are cross resistances between different sub-groups of herbicides within a group. This assumption is false. Data have shown that within the Group B herbicides for example, resistance to Eclipse® does not mean that there is always cross resistance to Logran®. There are various patterns of resistance across Group B herbicides because resistance to this group can be endowed by several different mutations of the ALS gene. Another classic example comes from the Group C herbicides where there is absence of cross resistance between the triazines (simazine, atrazine) and the nitriles (bromoxynil) or ureas (diuron).

Apart from herbicides which need to be carefully managed because they have been seen by farmers as the best way of controlling wild radish, the best resistance management strategy is actually one of Integrated Weed Management (IWM) where all types of weed control, chemical and non-chemical, are combined.

MANAGING THE SEEDBANK

Running down the existing seedbank is the key strategy in the management of wild radish. There are various techniques available for managing the seedbank effectively. Reducing/preventing seed production, reducing/preventing seeds returning to the soil and reducing seed and seedbank longevity are direct techniques while altering the growth conditions to favour the crop but not the weed is an indirect technique.

Reducing/preventing seed production

Reducing or preventing seed production is paramount. Wild radish plants producing up to 45,000 seeds/m² in a wheat crop have been documented. In the northern agricultural region of WA, the presence of 5,000 seeds/m² is common occurrence. With such a high seed output, preventing seed production will be an effective way of minimising recruitment to the seedbank.

Under continuous cropping systems, crop topping and blanket wiping are two techniques that have been well-trialled. Under a pasture phase, there are more techniques available.

Crop topping

Generally, crop topping with non-selective herbicides at crop maturity will result in about 50-60 per cent reduction in viable wild radish seed levels. But our recent work in WA has shown that up to 97 per cent seed set control with no impact on lupin yield could be obtained using Logran®. Eclipse®, on its own or in combination with Brodal Options® or Sniper® have also been found to be effective when applied as a selective spray-topping treatment immediately after lupin flowering. Up to 98 per cent seed set reduction of wild radish were recorded when treatments were on a population susceptible to Eclipse®.

Blanket wiping

Crop damage from blanket wiping remains a problem in some years because of the inadequate height difference between weed and crop. In low crops such as lentil and chickpea, height difference is not an issue. Other issues include dripping of herbicide and or escapes of wild radish below crop canopy at time of wiping.

The following mixtures have given between 85-96% seed set control when applied on post embryo wild radish:

Roundup CT® 1 L + Glean® 10 g

2,4-D amine 1 L + Glean® 20 g

Roundup CT® 1 L + Eclipse® 10 g

Spray.Seed® 1 L + Glean® 10 g

Reglone® 1 L + Glean® 10 g

Inclusion of pasture phases

The inclusion of pasture phases into crop rotations is another effective way of reducing wild radish seed production. It allows the use of alternative weed control options not available during continuous cropping. Options such as intensive grazing/spray grazing, blanket wiping, cutting pasture for hay or silage, green and brown manuring are effective for reducing wild radish seed set by up to 100% for subsequent years. Brown manuring is a more effective method than mowing or slashing because it is less likely to result in regrowth of the wild radish.

Reducing/preventing seeds from reaching soil surface

Seed collection

Although seed collection at harvest is a feasible technique, it is not widely practised. Seed collection efficacy at harvest is reduced by early maturing wild radish plants with abundant seed production. These plants tend to shed a high proportion of their seed before harvest. Victorian work has shown that 59 per cent of wild radish pods had been shed before lupin harvest and between 48 and 56 per cent before wheat harvest. Nevertheless, early windrowing (swathing) of crops like canola and pulses may prevent return of wild radish seeds to the soil by capturing the green wild radish pods.

Hygiene

The importance of hygiene should not be under-estimated. With proper hygiene, it will help to prevent the spread of wild radish seeds by farm machinery, hay and crop seed. Surveys in Victoria and New South Wales have shown that crop seed contaminated with wild radish seed is still common.

It is good practice to quarantine stock that have recently consumed wild radish. It takes 2-5 days for sheep to pass out the majority of seeds.

Hygiene is vital in the prevention of spread of triazine resistance in wild radish because radish seed is the only means of spreading the gene, not the pollens.

Reducing seed and seedbank longevity

A weed like wild radish which has long-term seed dormancy must be tackled over a number of years, either by preventing or stimulating seed germination, when manipulating its seed and seedbank longevity.

Autumn tickle

A light cultivation or 'tickle' is an effective way to encourage emergence of wild radish thereby running down the seedbank. Subsequent control of this early germination with a knockdown herbicide prior to seeding could reduce the wild radish seedbank by over 50%, as noted at one site in Merredin (Table 1).

Table 2. Effect of autumn tickle on seedbank of wild radish at Merredin, WA

Soil treatment	Seedbank reduction (%)
Tickle	55.5
No tickle	4.3

Shallow cultivation places seeds in the top 2 cm of the soil profile which is ideal for germination, in contrast to deep cultivation which prevents the deeply buried seeds from germinating. In fact, wild radish seed persistence is greatest when seed is buried deeper than 4 cm.

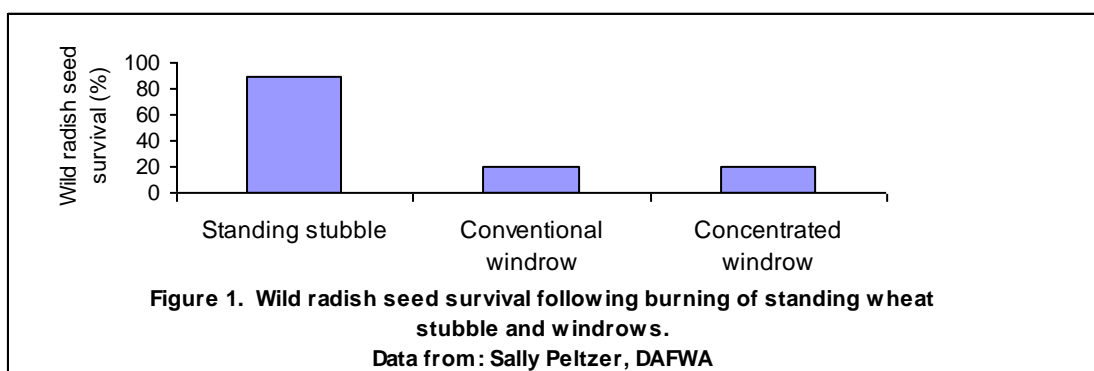
The fact that buried seeds prefer exposure to light and surface seeds prefer darkness for germination partly explains the stimulation of germination brought about by cultivation. Cultivation changes the position of seeds in the soil and therefore access to or shelter from light. The physical damage to the seed pod by cultivation could also reduce the dormancy of the seed.

Tillage systems that place wild radish seed at varying depths will therefore affect seed longevity. Since shallow burial of seed is ideal for germination, shallow burial is the best approach to reduce seedbank longevity. To maximise seedbank decline, confining wild radish seeds to shallow depths is therefore essential.

How long does the seedbank persist is one of the most frequently-asked questions. Various studies have shown that if there is complete or near-complete seed set control, the greatest decline occurs during the first 4-5 years. As much as 98% of the seedbank could be depleted in 5 years under complete seed set control but 93% over the same period under near-complete control in rotations involving chemical and non-chemical control options. This is equivalent to 50% decline each year. Because very effective measures are available to prevent wild radish seed production during the pasture phase, the rate of seedbank decline is the fastest. Whether an acceptable seedbank is reached after 5 years very much depends on the size of the initial seedbank and our ability to achieve complete or near-complete control every year.

Burning

Burning is another effective way of reducing the seed longevity by killing wild radish seeds present on the soil surface. Although there are dangers of soil erosion after burning, there may be time when burning is an appropriate tool to use. Research carried out by DAFWA and WAHRI showed that burning standing wheat stubble did not sufficiently increase the temperatures to destroy wild radish seed. But when either lupin or wheat stubble residues were concentrated in windrows, soil surface temperatures were hot enough to kill any wild radish seed present on the soil surface (Figure 1).



Altering growth conditions

Altering growth conditions to favour the crop but not the weed indirectly affects the seedbank. The use of rotation involving both crops and pastures, the choice of crop and seeding rate and other practices all have a role in the management of wild radish.

CONCLUSION

Best management practice for wild radish like all other weeds, involves IWM and it is a long-term business. As wild radish germinates throughout the year and over many seasons, effective management requires a thorough and persistent weed control program for several seasons to minimise fresh seed input and to run down the existing seedbank. To achieve this, strategic use of the management tools mentioned together with the adoption of effective crop, pasture and herbicide rotations will lead to cost-effective wild radish management, delay herbicide resistance and sustain profitable production. Because of the wide range of weeds, crops, soils, climate and herbicides found in all Australian States, it is not possible to be specific in working out detailed management program which would be practical for a large number of farmers. However, individuals could make a start to developing an effective management program by thinking of the amount of seed produced by the wild radish and to stop thinking only of the amount of seed produced by the crop.

KEY WORDS

wild radish, integrated weed management, seedbank

Paper reviewed by: J.R. Peirce

Control of phenoxy resistant wild radish through the combined effects of wheat competition and phenoxy herbicides

Natalie Maguire and Michael Walsh, WAHRI, School of Plant Biology, University of Western Australia

KEY MESSAGES

- The combination of phenoxy herbicide application and increased wheat crop competition resulted in the control of a phenoxy resistant wild radish population.
- Crop competition and phenoxy herbicide application did not control more robust phenoxy resistant wild radish population.
- Continued use of phenoxy herbicides to control phenoxy resistant populations is only a short term solution.

AIMS

To investigate the combined impact of wheat crop competition and the application of 2,4-D amine on the growth and survival of two 2,4-D amine resistant wild radish populations (WARR 12 and WARR 20).

METHODS

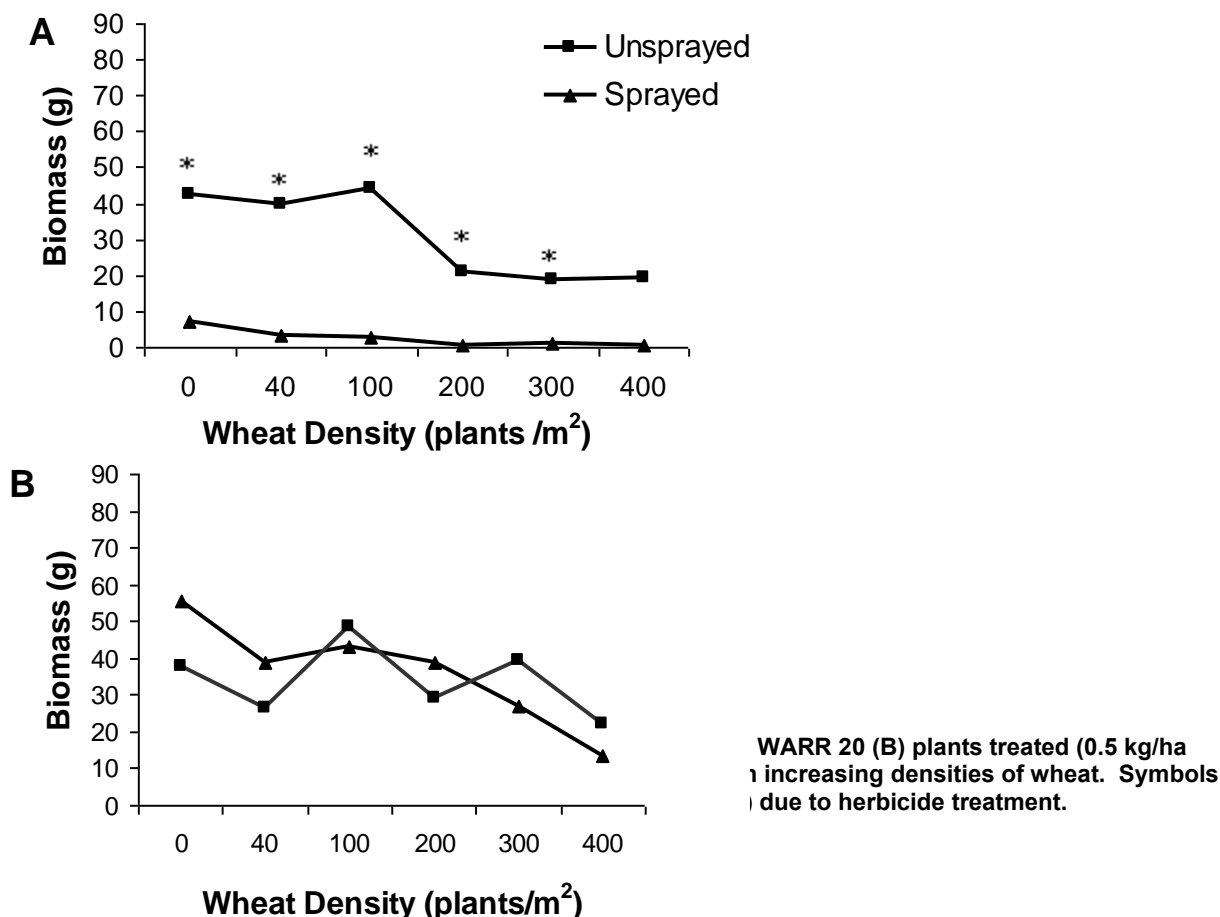
A target-neighbourhood design pot experiment was used to assess the influence and interactions of herbicide application, wild radish population type and wheat competition on the biomass of two phenoxy resistant wild radish populations. The target species (wild radish) was maintained as a single individual plant surrounded by increasing densities of neighbourhood species of wheat plants. Six densities (0, 40, 100, 200, 300 and 400 plants/m²) of wheat plants were used. Half of the treatment pots were sprayed with the recommended rate (0.5 kg/ha) of 2,4-D amine and the other half were left to grow in the absence of herbicide treatment. Assessments on above ground biomass of both species were made once wheat had reached the flowering stage.

RESULTS

The possibility of the continued use of phenoxy herbicides for the control of phenoxy resistant wild radish populations was indicated in these studies. At wheat maturity complete control of the resistant WARR 12 population was achieved through the combined effects of wheat competition and phenoxy herbicides. Despite this population being resistant to phenoxy herbicides, application at the recommended rate of 2,4-D amine, caused significant ($P < 0.05$) reductions in biomass of sprayed plants when compared to the unsprayed WARR 12 plants (Figure 1A).

Increased crop competition due to higher plant densities resulted in substantial wild radish biomass reductions. In the absence of herbicide there was a 45% reduction in biomass between the 100 plants/m² and 200 plants/m² wheat densities (Figure 1A). These wheat plant densities relate to seeding rates of approximately 45 and 90 kg/ha respectively.

The combination of increased plant densities and phenoxy herbicides is unlikely to result in the control of all phenoxy resistant wild radish populations. The combined effect of wheat plant density and 2,4-D amine was not effective in controlling both phenoxy resistant wild radish populations. There was no effect on the WARR 20 population (Figure 1B), reflecting the robust and highly resistant nature of this population. This population was not controlled primarily because there was no effect on the wild radish plants. Biomass reductions due to increased crop competition occurred both in the presence and absence of 2,4-D amine application (Figure 1B).



The evolution of resistance to phenoxy herbicides in wild radish populations does not necessarily mean that these herbicides are no longer useful in the control of these populations. This study has shown that some resistant populations are still affected when treated with phenoxy herbicides. It has been demonstrated that effective control of resistant populations through a combination of wheat competition and phenoxy herbicide application has the potential to be used as a control option on at least some phenoxy resistant wild radish populations. However, the continued use of these herbicides may lead to the evolution of populations such as WARR 20, which contain more robust levels of resistance to phenoxy herbicides.

KEY WORDS

wild radish, phenoxy herbicides, 2,4-D amine, wheat competition

ACKNOWLEDGMENTS

The authors wish to thank the WAHRI staff for their contributions and support in the conduct of this research. This research was financially supported by the GRDC. This research comprises part of Natalie Maguire's 4th year honours project for which she received a Weeds CRC scholarship.

Project No.: UWA 399

Paper reviewed by: Mechelle Owen

Efficacy of florasulam on chlorsulfuron resistant and susceptible wild radish populations in Western Australia

Michael Walsh¹ and Dan Cornally², ¹WAHRI, School of Plant Biology, University of Western Australia, ²Dow Agrosiences Australia

KEY MESSAGES

- Florasulam at the 10 g a.i./ha rate provided complete control of over 90% of wild radish populations randomly collected from across the WA wheatbelt.
- There is a potential, at least in the short term, for this herbicide to provide good control of WA wild radish populations.

AIMS

This study evaluated the efficacy of florasulam on wild radish populations collected as part of a random survey. Populations known to be chlorsulfuron resistant were also included in the screen to determine if they were resistant to florasulam.

METHODS

Randomly collected wild radish biotypes from the WAHRI seed collection were screened for resistance to four ALS-inhibiting herbicides – chlorsulfuron, triasulfuron, metosulam and florasulam. A total of 74 populations were screened, 70 from the survey collection, a known susceptible (WARR25) and three known ALS-inhibiting herbicide resistant populations (WARR3, WARR6 and WARR30).

Seed from these populations were planted into foam boxes (50 cm x 30 cm x 15 cm) containing potting mix (25% river sand, 25% peat moss and 50% mulched pine bark v/v). The foam boxes were maintained in the outdoor pot growing area at UWA where they were watered and fertilised as necessary to maintain healthy plant growth for the duration of the trial. Two populations of approximately 50 plants each were established in each foam box.

When wild radish plants had reached the two leaf stage herbicide 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 km/h and 210 Kpa pressure. The herbicide treatments detailed in Table 1, all included 0.5%v/v Uptake Spray oil.

Table 1. ALS inhibiting herbicide treatments applied to wild radish populations at the two-leaf stage

Treatment	Rate (g a.i./ha)
Florasulam (50 g/L)	2.5, 5, 10
Metosulam (714 g/kg)	2.5, 5, 10
Chlorsulfuron (750 g/kg)	15
Triasulfuron (750 g/kg)	13

Twenty-one days after treatment, surviving plant numbers were recorded and data were converted to % survival for each population by herbicide treatment combination. It was assumed that any plants that survived herbicide treatment were resistant. Therefore, for the purposes of this study, only populations that contained no survivors were considered to be completely controlled.

RESULTS

Florasulam at the highest application rate was the most effective herbicide in controlling wild radish populations. Less than 7% of the 74 wild radish populations had any plants that were able to survive the 10 g/ha application rate of florasulam (Figure 1). When the application rate was halved to 5 g/ha, almost 25% of populations contained surviving plants. At the lowest rate of florasulam (2.5 g/ha), approximately 35% of the wild radish populations contained surviving plants.

In comparison, more than 30% of the same populations survived the highest rate of metosulam (10 g a.i./ha), and over 50% of populations had plants that survived the lowest application rate (2.5 g/ha). There was not a corresponding increase in the proportion of populations that were completely controlled when the application rate of this herbicide was increased to 5 g/ha.

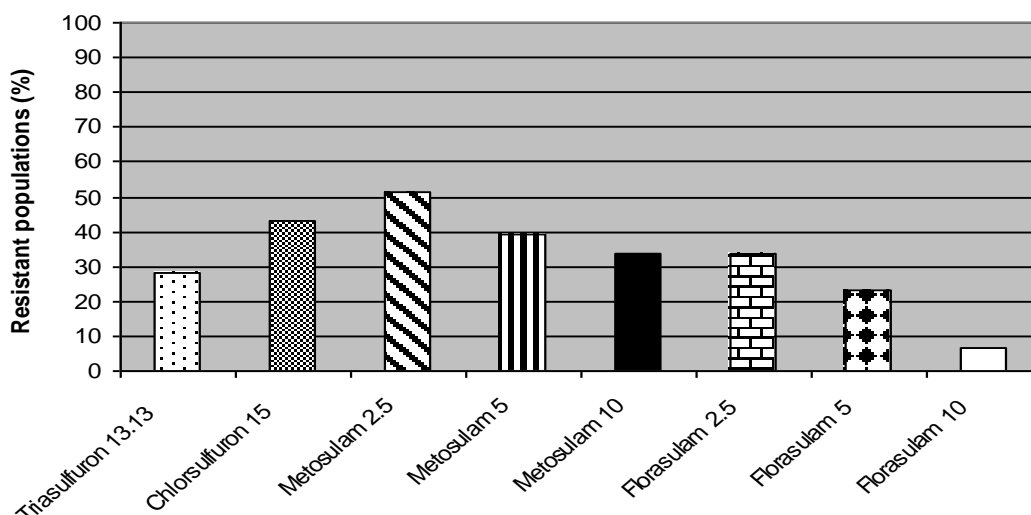


Figure 1. Proportion of wild radish populations that had at least one plant surviving the application of an ALS inhibiting herbicide treatment.

There was a large variation in the number of populations with plants surviving the different ALS inhibiting herbicide treatments. A high proportion (43%) of wild radish populations survived the recommended rate of chlorsulfuron (15 g/ha) and 28% of the populations had survivors at the recommended rate of triasulfuron (13 g/ha).

The only mechanism currently identified which confers resistance to the ALS-inhibiting herbicides in wild radish populations is an altered target site, which results in the ALS enzyme being insensitive to these herbicides. There are a number of different mutations that result in an insensitive ALS target site in wild radish and these mutations generate different patterns of cross-resistance between the ALS-inhibiting herbicides. The variation in the proportions of populations surviving these sulfonyl-urea herbicides indicates that there are different mutations present within the wild radish populations tested, each with their own pattern of herbicide tolerance.

As part of the study we examined the geographical spread of the resistant biotypes. Five regions were identified, ranging from region 1 in the northern part of the wheatbelt to region 5 in the southernmost area of the wheatbelt. The proportion of wild radish populations surviving all ALS-inhibiting herbicides was highest from region 1 (Figures 2 and 3). Over 70% of wild radish populations from this region had plants that survived all treatments except for the two high rates of florasulam (Figure 3). Even in this region with widespread ALS resistance, florasulam at the 10 g a.i./ha rate was the most effective treatment. Florasulam at the high rate gave complete control of approximately 80% of the populations screened. Regional survival levels of wild radish populations were substantially lower in all other regions. The trend was for increasing population control from region 1 to region 5 with the same pattern between the active ingredients.

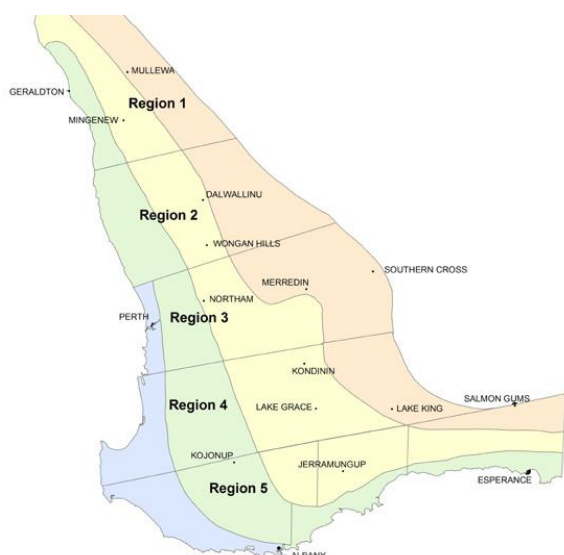


Figure 2. Agronomic regions of the Western Australian wheatbelt.

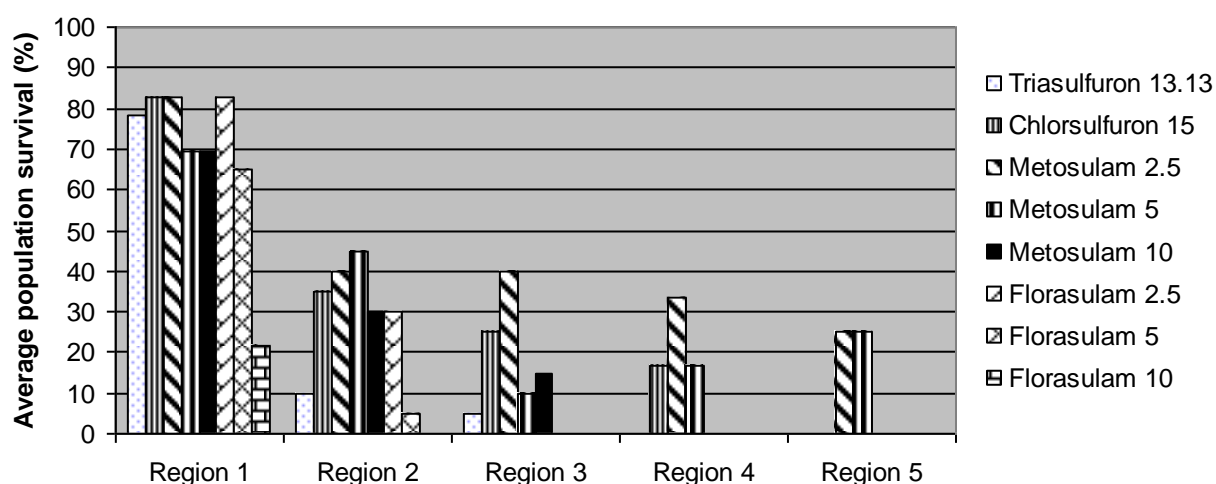


Figure 3. Proportions of populations surviving ALS-inhibiting herbicide treatments in each of the five regions of the WA wheatbelt.

The three wild radish populations from the WARHI collections, previously characterised as being resistant to ALS inhibiting herbicides were also found to be resistant to the ALS-inhibiting herbicides used in this study. On average there were very high levels of plant survival for all three populations screened with the eight herbicide treatments (Figure 3). The exception was WARR3, where at the highest rate of florasulam, there was less than 20% population survival. There was also a rate response effect for this population with decreasing levels of survival at increasing applications rates. The most resistant population in terms of percent of the population surviving herbicide treatment was the WARR 30 population. This population had at least 80% survival across all the ALS-inhibiting herbicide treatments.

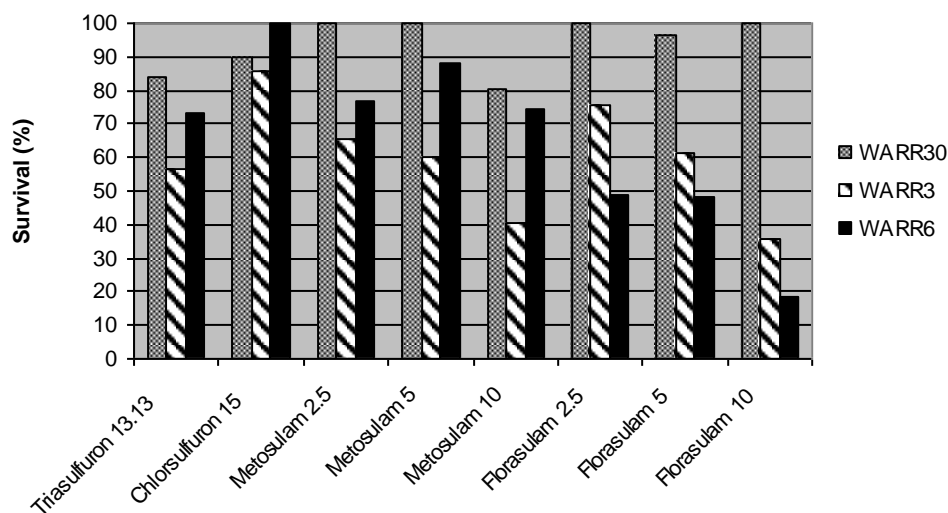


Figure 4. Proportion of plants of three resistant wild radish populations surviving ALS herbicide treatments.

CONCLUSIONS

Florasulam at the highest application rate provided the greatest level of control across the field collected populations screened in this study. Additionally there was an unexpected rates response where substantially fewer populations were controlled at the lower application rates. This rate response was not as evident for metosulam. Given that target site resistance results in a robust level of resistance to ALS-inhibiting herbicide resistance in wild radish populations, these results are unusual. Based on the large number of populations screened and the consistent results, there appears to be a niche for florasulam to control wild radish in WA. However, the presence of populations that are apparently already resistant to this herbicide would indicate that continued reliance on florasulam could be expected to select for increased numbers of populations able to survive florasulam treatments.

Project No.: UWA 399

Paper reviewed by: David Minkey

Does liming to increase soil pH limit the growth and development of wild radish (*Raphanus raphanistrum*)?

Matt Willis and Michael Walsh, WAHRI, School of Plant Biology, University of Western Australia

KEY MESSAGES

- In the absence of crop competition liming to increase the soil pH had no effect on wild radish growth and development
- In the presence of wheat competition, increasing the soil pH by liming resulted in a 41% reduction in the aboveground biomass of wild radish.

AIMS

To investigate the impact of liming to increase soil pH on the growth and development of wild radish plants. Also to determine if an increase in the soil pH resulted in a reduction in competitive ability of wild radish in cropping systems.

METHODS

Soil was collected from the 2006 Mingenew Irwin Group (MIG) trial site and used in a laboratory study to establish a lime response curve (data not presented). This curve was then used to identify lime application rates for a pot and field trials conducted at the University of Western Australia (UWA), Nedlands campus and the MIG trial site respectively.

Liming treatments in the pot experiment were established by thoroughly mixing measured amounts of Dongara lime with soil collected from the MIG trial site. These soils were then moistened and allowed to incubate in a glasshouse in bags for two months. This method was used to establish eight soil pH treatments. The soils were transferred into foam boxes measuring 50 x 30 cm with six wild radish plants established in each box. Six replicates were used for each treatment. Plants were harvested for the determination of root and shoot biomass production once half of all plants had commenced flowering.

The field experiment was established by incorporating (cultivating) six application rates of Dongara lime into 2 x 20 m plots at the MIG trial site on 13 April. Plots were planted to wheat on 3 July and 14 days later wild radish seedlings were transplanted into the plots at a density of 1 plant/m². Wheat and wild radish plants were harvested at wheat anthesis on 13 October for the determination of aboveground biomass.

RESULTS

Pot study

The results from this study were highly variable, however, there was an indication only of increased levels of wild radish biomass at higher soil pH values (Figure 1). The increase in shoot biomass with increasing soil pH levels was not significant ($P > 0.05$) due largely to the high variability in shoot biomass values. This variability is largely due to the high genetic variability of wild radish resulting to a high degree of phenotypic plasticity. The inconsistency in growth primarily occurred in the production of above ground biomass. Therefore, despite a trend for increasing shoot biomass with increasing application rates of lime the naturally variability in wild radish plant growth prevented these differences from being significant.

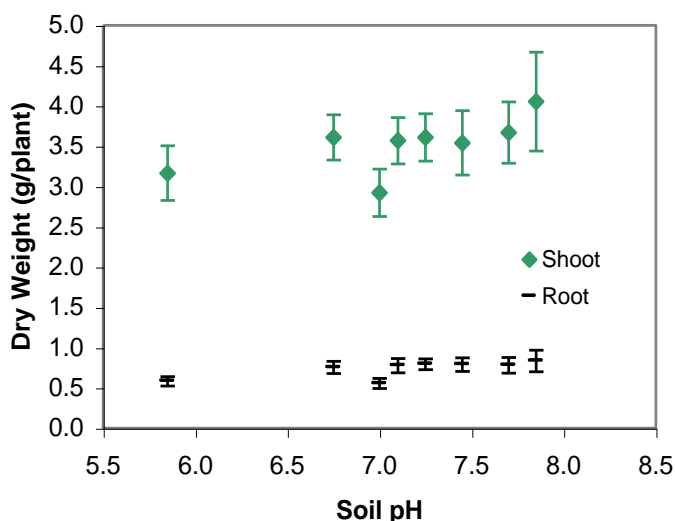


Figure 1. The effect of soil pH on the wild radish shoot and root biomass of plants grown in the pot experiment. Bars represent standard errors of the observed values for six replicates.

Field trial

In the field competition study a reduction in the aboveground biomass of wild radish plants was observed with increasing soil pH. Despite the variability in the plant biomass data and subsequent lack of significant effects it was apparent that above ground wild radish biomass decreased with increasing soil pH levels at the field site (Figure 2). Plant growth in general, was restricted by the very dry growing season that may have masked significant results. There was no difference ($P > 0.05$) in wild radish biomass between any of the liming treatments. Despite this, there appeared to be a trend for decreasing plant biomass with increasing soil pH values. In fact there was a 41% reduction in wild radish biomass between the lowest and highest soil pH levels.

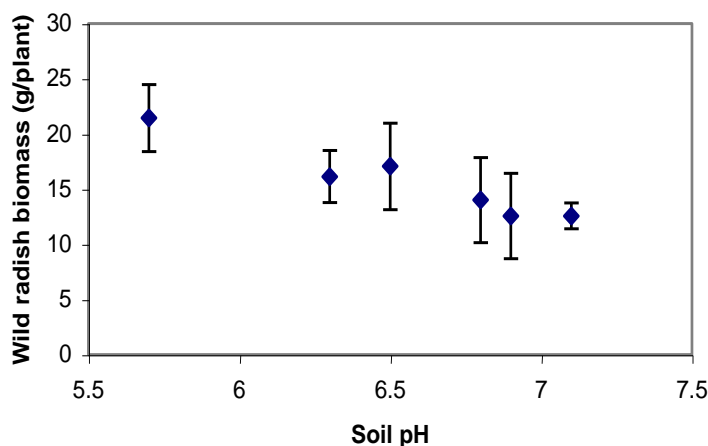


Figure 2. The effect of soil pH on wild radish plant biomass. Bars represent standard errors of three replicates.

There was no effect of liming treatments on the dry weights of wheat plants growing on soils with increased pH levels at the Mingenew field site (Figure 3). Therefore, in this study the biomass of wheat has not been affected by the addition of very high amounts of lime that subsequently resulted in large changes in soil pH values. Therefore, changes in wild radish biomass observed above are likely due to the enhanced competitive ability of wheat for limited resources at higher soil pH levels. With no real increase in above ground biomass of wheat reduced wild radish biomass is not due to shading.

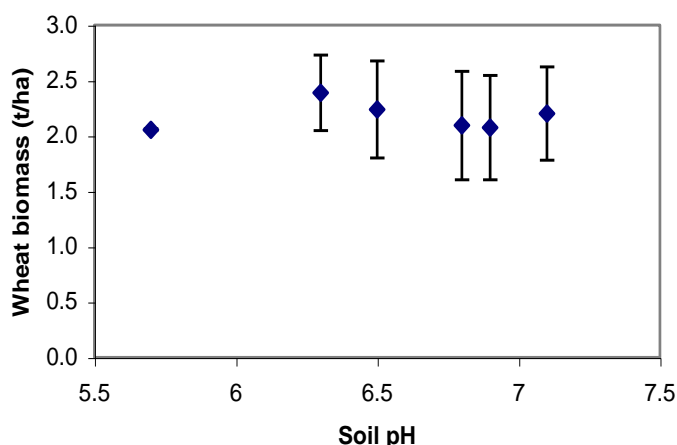


Figure 3. The effect of soil pH on wheat biomass. Bars represent standard errors of three replicates.

CONCLUSIONS

In the presence of a wheat crop the results from this study indicate that wild radish is at a competitive disadvantage when the soil pH is increased by liming. Large reductions in wild radish plant biomass was recorded when the soil pH was increased from 5.7 to 7.1 at the MIG trial site. However, the variability in the biomass data prevented this response from being significant. Therefore, additional studies are required to confirm this observation. In the absence of competition there was an apparent increase in wild radish biomass with increasing soil pH values. These results indicate that at higher soil pH levels wheat is more competitive for limited soil nutrient resources than wild radish.

KEY WORDS

wild radish, soil pH, crop competition, liming

ACKNOWLEDGMENTS

The authors wish to thank the WAHRI staff for their assistance and support in the conduct of this research. This research was financially supported by the GRDC. Thanks also to Debbie Allen for her help in the conduct of the field trial at the MIG trial site. This research comprises part of Matt Willis' 4th year honours project for which he received a GGA scholarship.

Project No.: UWA 399

Paper reviewed by: Dr Roberto Busi

Weed trimming – a potential technique to reduce weed seed set

Glen Riethmuller¹, Abul Hashem² and Shahab Pathan¹, Department of Agriculture and Food, Western Australia, ¹Merredin and ²Northam

KEY MESSAGES

Weed seed head trimming prior to weed seed maturity may be useful in reducing the number of weed seeds set if the weed seed heads are above the crop canopy and the cutting height is controlled. This is a non-chemical way to reduce the soil weed seed bank.

AIMS

To test if trimming or cutting weed seed heads above the crop prior to weed seed maturity can reduce the weed seed-bank.

METHODS

Selective spraying at the flowering stage of weeds, blanket wiping or crop topping at crop maturity are often performed to reduce weed seed set. These practices involve increased frequency of herbicide applications that may contribute to the development of resistance. Although swathing is a physical way of preventing weed seed set in some crops such as canola, the greatest limitation of this practice is many weeds seeds would mature before swathing is done and mature seeds are likely to shatter. Weed seed shattering, with or without swathing, is also a serious limitation of weed seed collection at harvest. One way to reduce this problem is to remove the weed seed heads at the flowering stage before seeds are mature.

At flowering stage, some weed heads are much taller than the canopy of crops such as chickpea, field pea and lupins. A swather or header that can be raised above crop canopy may be used to cut the seed heads of weeds with minimum damage to crops in a tramline farming system. This will reduce the fresh inputs to the seed bank. Preliminary results on weed seed head removal by hand cutting late in the 2004 season at Merredin showed that 79% of the wild radish pods and 47% of the ryegrass heads were above the lupin canopy and were removed by hand cutting without damaging the crop (Pathan, unpublished data).

Experiments were conducted in 2005 at Merredin and in 2006 at Merredin and Wongan Hills. A commercial swather was not available in Merredin so an 11 m wide header front was converted to swathing (Photo 1) while a 5 m wide PTO swather was used at Wongan Hills. Treatments included untreated, trimming weed heads at the maximum flowering stage of the weeds, trimming at the late flowering stage, and trimming both at the maximum and late flowering stage of weeds. Weed seeds were collected from the cut material and seed viability was determined.



Photo 1. The header front used to trim wild radish and wild oats heads above a chickpea crop at Merredin in 2006.

RESULTS

Weed seeds collected from the weed seed heads cut at the early flowering stage of weeds (14 September) in 2005 at Merredin showed no viability of wild oats or wild radish seed tested in 2006 after a dormancy break period of 11 months. The weed seed heads cut at the late flowering stage of weeds (5 October) showed no viable wild radish seed but up to 40% of seed viability was observed in the wild oat seed.

It was also observed that the wild radish took around two weeks to regrow after the first trimming so this may help delay the development of some wild radish pods allowing crop topping to be more effective on the weeds. The lupin yield was reduced by the trimming techniques, which may have been due to the cutting height set too close to the top of the crop (Table 1).

Table 1. Lupin grain yield and visual rating with time of weed trimming at two stages of weeds at Merredin and Wongan Hills

Treatment	2005 Merredin Lupin yield (t/ha)	2006 Merredin Lupin yield (t/ha)	2006 Merredin weed visual rating above canopy 14 October (%)	2006 Wongan Hills Lupin yield (t/ha)
1. Untreated	0.948a*	1.63a	13.7a	0.553a
2. Maximum flower	0.842ab	1.72a	5.9 b	0.556a
3. Late flower	0.817ab	1.72a	3.9 b	0.741a
4. Maximum and late flower	0.718 b	1.80a	4.7 b	0.621a
p-value	0.022	0.267	0.006	0.377
Isd (p < 0.05)	0.131	ns	4.1	ns
C of V (%)	9.8	6.0	21.2	26.2

* Values with the same letter are not significantly different (p < 0.05).

Two cuts reduced yield even further, which suggests that lupin pods were being cut off. The entire crop yield was in the top of the canopy (there were no pods on the main stem) probably due to the frost damage to pods formed earlier so this probably contributed to the general reduction in lupin grain yield.

The wild radish seed number collected at harvest showed no treatment effect, which was probably due to the variation in density and patchiness of the wild radish plants above the crop canopy.

In 2006, the cut height was just above the lupin canopy and the lupin grain yield was not affected by trimming (maximum flowering 20 September, late flowering 13 October) at Merredin (Table 1).

A visual rating of the percentage of wild radish left above the crop canopy after the late flowering stage cutting at Merredin showed the trimming to be very effective in reducing seed set (Table 1).

The wild radish and wild oats seed collected in the harvested grain was used as an indication of the effectiveness of the trimming treatments but since the untreated treatment had shed most of the seeds before harvest it was not a good measure of effectiveness even though all trimming treatments appeared to reduce the weed seed numbers by about half compared to the untreated.

At Wongan Hills, the wild radish density was high and variable across the site. The lupin yields were similar for all treatments (max flower 25 September, late flower 6 October) (Table 1) and there appeared no treatment effect on the wild radish seed number collected in the harvested grain.

In 2005 at Merredin, chickpea yield was generally low regardless of treatments due to frost damage. One trimming at either stage produced statistically similar yields to the untreated control although two trimmings reduced chickpea yields in 2005 compared with the untreated control (Table 2). The number of Indian hedge mustard seed collected in the harvest samples were significantly reduced in all trimming treatments in 2005 (Table 2).

Chickpea yield was not affected by trimming treatments in 2006 (Table 2). The numbers of wild oat seeds in the harvested grain were also significantly reduced by trimming at the late flowering stage although most of the wild oat seeds had shed before harvest. If wild oats is the main weed in a chickpea crop, perhaps one cut at late flowering stage will be useful and an early harvest may capture more wild oat seeds.

Table 2. Effect of trimming on chickpea grain yield and weed seed number in the harvested grain

Treatment	2005 Chickpea yield (t/ha)	2005 Indian hedge mustard (seed/m ²)	2006 Chickpea yield (t/ha)	2006 Wild oats (seed/m ²)	2006 Volunteer Wheat (seed/m ²)
1. Untreated	0.422a*	223a	0.523a	1.30a	0.85a
2. Maximum flower	0.467a	145 b	0.472a	1.04a	0.12 b
3. Late flower	0.486a	154 b	0.455a	0.03 b	0.02 b
4. Max and late flower	0.347 b	137 b	0.466a	0.19 b	0.00 b
p-value	0.005	0.007	0.685	0.066	0.024
lsd (p < 0.05)	0.064	40.5	ns	0.63	0.325
C of V (%)	9.2	14.2	17.6	71.5	101.2

* Values with the same letter are not significantly different (p < 0.05)

CONCLUSION

Weed seed head trimming may be useful for reducing the number of weed seeds set particularly in a tramline farming system if the weed seed heads are well above the crop canopy and the cutting height is controlled.

Indian hedge mustard seed collected in the 2005 chickpea harvest samples was reduced by around 35% with all trimming treatments. In 2006 the late flower trimming reduced the seed number of wild oats and volunteer wheat above chickpeas.

Given the difficulties in controlling weeds by the growers due to widespread development of herbicide resistance by these weeds within the WA wheatbelt, this novel non-chemical way of weed control is a viable promising option to reduce soil weed seed bank.

This technique did not appear as useful for ryegrass, possibly due to the relatively weak stems being pushed away by the knife.

Future work needs to measure the weed seed number already shed before harvest to get a better measure of trimming effectiveness.

KEY WORDS

weed seed head trimming, seed set, seed bank, wild radish, wild oats

ACKNOWLEDGMENTS

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Paper reviewed by: David Bowran

Burn narrow windrows in the wind

Peter Newman¹ and **Michael Walsh²**, ¹Research Officer, Department of Agriculture and Food, Western Australia, ²Research Fellow, WA Herbicide Resistance Initiative

KEY MESSAGES

Narrow windrows burn hotter for longer than conventional windrows or standing stubble. This results in improved destruction of weed seeds. Burning narrow windrows in light wind helps to fuel the fire with oxygen and improves the reliability of destroying weed seeds at the soil surface.

AIMS

To demonstrate the safest and most reliable technique to destroy weed seeds with burning.

METHOD

The effectiveness of burning narrow windrows of wheat, lupins and canola stubbles in killing annual ryegrass and wild radish seed was evaluated over four seasons in the northern wheatbelt region of Western Australia. Kiln studies were conducted to determine the temperature and duration required to destroy wild radish and annual ryegrass seeds.

Temperatures were recorded during burning of the stubble treatments at one to five second intervals using high temperature type K thermocouples (composed of NiCu/NiAl) connected to a CR10X Campbell Scientific datalogger. Thermocouples were placed at a range of heights beneath or above the soil surface to record the temperature and duration of the burning treatments.

RESULTS

Preliminary kiln studies determined that temperatures in excess of 400°C for at least 10 seconds was needed to guarantee the death of ryegrass seed. 500°C for the same duration was required to kill wild radish seed within their pod segments.

Standing stubble versus windrow stubble burning

The conventional windrow and narrow windrow treatments burnt at higher temperatures over a much longer period than the standing stubble (Figure 1).

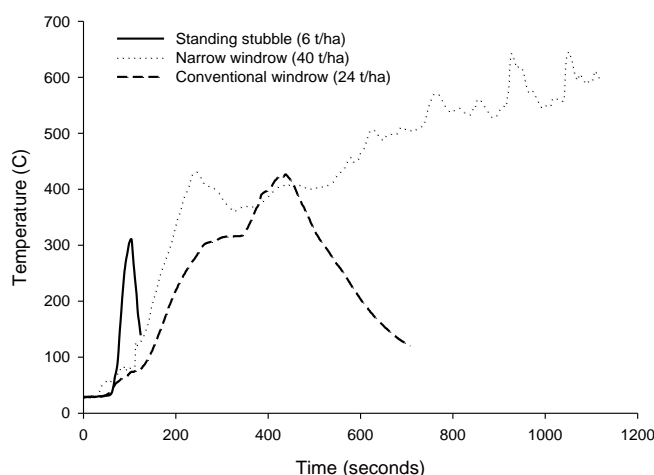


Figure 1. Temperatures recorded during burning of standing wheat stubble, stubble in a conventional windrow and a stubble in a concentrated windrow at Konongorring in 2004.

Wind speed effects on narrow windrow burning

The high wind speed treatment produced the highest burning temperature and the shortest burning duration. The medium wind speed burnt slightly hotter than the low wind speed treatment (Figure 2).

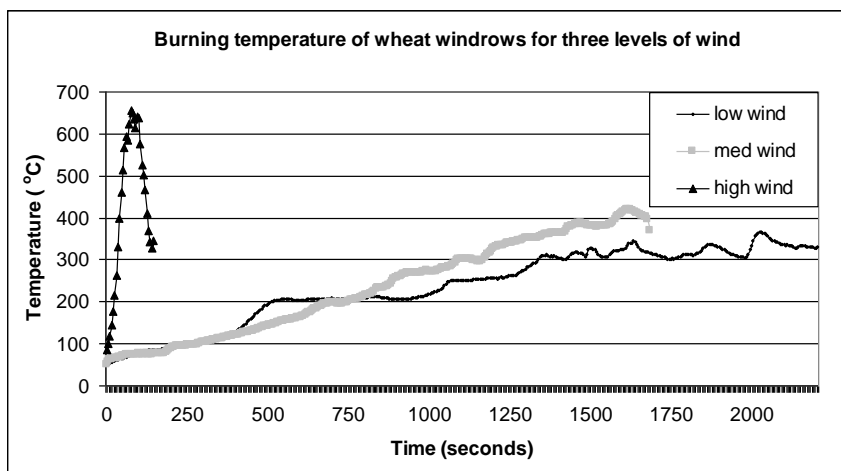


Figure 2. Effect of wind speed on the burning duration and burning temperature at the soil surface of wheat stubble in narrow windrows.

CONCLUSION

Narrow rows maximise burning temperature and duration due to the high biomass present in the windrow. Narrow windrows improve the reliability of burning only the windrow compared to conventional (wide) windrows. Burning entire crop stubbles results in a high risk of wind erosion and is therefore not recommended for most paddocks in Western Australia.

Many growers are accustomed to burning stubbles in still conditions to avoid the fire getting away. High wind speeds of 24 km/h are clearly not practical. Moderate wind speeds of 5 to 10 km/h are practical and appear to be improving the reliability of burning a windrow all of the way to the soil surface at temperatures sufficient to kill weed seeds. Observations made during burning were that in some instances, in low wind conditions, the layer of burnt ash from the initial burn smothered the chaff below, reducing the ability of the windrow to burn to the soil surface.

The destruction of weed seeds using windrow burning is an important IWM tool that is now widely adopted by growers in Western Australia. The adoption of 'chaff carts' and the baling of straw as it exits the harvester has been limited due to financial and practical reasons.

The collection of harvest residues in 'chaff carts' facilitates the removal of 75 to 85% of ryegrass seed and 70 to 80% of wild radish seed that enters the harvester (Walsh and Parker 2002). If windrow burning generates temperatures high enough to destroy all weed seeds present, then similar levels of weed seed control can be expected from burning narrow windrows as chaff collection in a chaff cart or bailing residue directly from the harvester.

KEY WORDS

windrow, burning, wild radish, annual ryegrass

ACKNOWLEDGMENTS

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Paper reviewed by: Dave Minkey

Winning the Weed War with the Weed Seed Wizard!

Michael Renton, Sally Peltzer and Art Diggle, Department of Agriculture and Food, Western Australia

KEY MESSAGES

A new computer tool called '**The Weed Seed Wizard**' is being created to help coordinate weed management by focussing on the weed seedbank.

AIMS

Are you waging war with your weeds? You may think that you are, but your real enemy is the bank of seeds lying hidden beneath the soil. No matter how many weed plants you kill this year, there will always be more seeds lying hidden in the seedbank ready to spring to life and cost you money by cutting your crops' yield. To win the war against weeds, you need to fight a long-term campaign. Instead of only focussing on the weed plants you see in the field, you need to target the weed seedbank; isolating it, cutting off its supply and thus slowly strangling it to death.

The weed seedbank is a formidable enemy for three main reasons. It is invisible, it is patient, and it is hard to understand. While weeds do their damage above ground by the light of day, their seeds lurk hidden beneath the ground. While most cropping weed plants come and go within a few months, their seeds can often wait happily for years until conditions are right. And while it may seem that the best way to control weeds is simply to kill the plants, the long-term fluctuations in weed numbers will be affected by the complex interaction of a large number of factors, including the seed and plant biology of a huge range of different species; competition between weeds and crops; the effects of tillage (or non-tillage), herbicides, harvesting options and other management techniques on soil, plants and seeds; weather and environment; and even seed-eating ants!

Experiments and field work are invaluable in telling us something about a particular factor influencing weed populations, such as the dormancy characteristics of a certain Mingenew wild radish population, the wild oat kill rate achieved by spraying a particular herbicide brew on a still cloudy day, or the way that an autumn tickle moves ryegrass seeds around in a sandy soil. However, due to practical limitations on time and resources, this kind of research is usually relatively short-term, involves fairly limited sampling of soil seed numbers and positions, and has to consider the interaction between just a few factors (at best). This gives us only limited insight into the questions of how to manage weed numbers in the long-term, with a whole heap of choices to make, regarding a whole heap of interacting factors, when many of these factors (such as the weather and whether you'll be busy watching the Dockers in September) are largely unpredictable.

One way to understand, predict and manage a system that is hidden beneath the soil and involves a large number of complex, long-term interactions is to create a computational model of that system. A computational model can integrate existing knowledge gained from a large number of focussed experiments and trials. By putting this information together, it can build a reasonable representation of the way things will work in a much wider range of interacting conditions, over a much longer time period. It can provide a window into the parts of the system that are usually hidden (the seedbank), and look at how they influence and are influenced by the parts of the system that directly affect us (the weeds) and the parts that we can control (management options). The aim of this work is to construct such a model – a model that can give us a 'big picture' view that lets us see the wood through the trees – or the paddock through the weeds! We want this model to be the basis of a practical decision-aid tool that can help farmers and consultants manage weed populations in real agricultural contexts, and win the war against these green invaders.

METHOD

The 'Weed Seedbank Wizard' is a simulation model and user-friendly decision-aid being developed to give insight into the hidden weed seedbank and help coordinate the long-term management of weeds. The model simulates important aspects of the interaction between weather, paddock management and seed biology, in order to track and predict the numbers, ages, soil depths, dormancy levels, viability and germination of seeds in the soil. The simulation is specific to the individual site, season and weed

species. The Wizard uses the simulation to predict both the amount of weeds appearing each year and the hidden reserves waiting in the seedbank, and thus warn of potential weed problems while they are still avoidable.

The Wizard can show how decisions regarding choice of crop, sowing date, seeding rate, tillage and grazing management, herbicide application and harvest options affect factors such as weed germination, weed density, crop yield and the long-term sustainability of your farm. It can also be used to explore how the seed dormancy, germination requirements, competitiveness, and herbicide resistance of different weed species or populations can strongly affect the choice of an appropriate management strategy. The Wizard lets the user easily experiment with any number of future strategies for managing weeds, and find one that is cost effective and stable.

A prototype of 'The Wizard' has been designed and implemented in the Java programming language. The model includes representations of the soil, the daily weather, the plant population, and the individual seeds within the soil. It simulates the moisture and temperature within the soil; the dormancy, after-ripening and germination of the seeds; the effects of competition between different plant species on seed set; and the effects of management actions on plants and seeds. A prototype graphical user interface (GUI) has been designed for the tool, which can run as a stand alone application, or within a browser window. The GUI includes windows where the user can adjust the initial conditions of the simulated paddock; add, delete or edit scheduled management actions; and view the simulated output regarding the states of the soil seedbank, plant populations, crop yield, etc. Different scenarios of weed management can be compared side-by-side, and the predicted effect of choosing one option or another can easily be observed. Standard data formats have been designed for required data on herbicides, plant species, types of cultivation and management scheduling. Routines have been implemented to read this data into the model.

While a functioning prototype of the Wizard already exists, the Wizard is a 'work in progress', with new weed species and management options being added regularly. The computational representations of the underlying biology and physics are also being tested and refined. The results of ongoing field trials will be used to further test and update the model. Just as importantly, the graphical interface that the user uses to interact with the model is being continually improved in the light of feedback received from those who have tried to use the tool.

The Weed Seed Wizard will soon be able to simulate and predict the seedbank dynamics of a wide variety of species. As a national project, with participants in Western Australia, South Australia, New South Wales and Queensland, it will target major in-crop annual weeds from each State. For Western Australia, target weeds include annual ryegrass (*Lolium rigidum* Gaud.), barley grass (*Hordeum leporinum* Link.), wild radish (*Raphanus raphanistrum* L.), wild oat (*Avena fatua* L.), brome grass (*Bromus* spp.) and silver grass (*Vulpia* spp.). Different weed species persist in the soil (or seedbank) for different periods. Some species have little or no dormancy and germinate with the opening rains, completely depleting the seed bank. Other species with dormancy require specific environmental (light, moisture, temperature, accumulated degree days, etc.) cues for dormancy to be broken and germination to commence. These species can persist for several years. The Wizard will incorporate the vast collection of existing documented knowledge about the different biology of each species.

The Wizard's predictions can be made very specific to individual paddocks and actual weather. The weather data (minimum and maximum temperature, rainfall and evaporation) can be drawn from internet databases for the nearest weather station, or entered from the farmer's own records (if available). The soil type, original weed population and management history can be specified separately for each paddock, or even different patches within the paddock (if necessary).

The Weed Seed Wizard will take into account conservation tillage systems (including No-Till and Zero-Till) combined with strategic use of a range of other techniques, such as soil inversion, autumn tickle, crop competition, selective and nonselective herbicides, crop topping, swathing, seed catching, and burning or grazing for stubble management. We envisage that the Wizard will operate as an adjunct to paddock record-keeping software, using farmer records concerning paddock management decisions, the site, and other observations. Such records might include crop sown, sowing date, seeding rate, tillage and grazing management, herbicide application, crop yield, weed density, rainfall, etc. The aim is to make the Wizard self calibrating (have the capacity to adjust its parameters in response to ongoing observation records to better predict weed populations in a particular paddock).

Eventually the Wizard might be part of a farm management system that integrates farmer record keeping with simulations of biological and physical processes including weed populations, soil water and nutrition, insect pests and diseases.

RESULTS

For any given schedule of management and weather events, the Wizard predicts annual crop losses due to weeds. If required, it can also produce more detailed output explaining these predictions, such as graphing the weed and crop density over time, or even giving such detail as plotting how the number of weed seeds at different depths in the soil changes with time.

An example is given in Figure 1, which shows the Weed Seed Wizard interface. The tabs at the top allow the user to switch between different scenarios and paddocks, or access windows where model parameters can be adjusted. The tab showing here is a 'Scenario Window' for 'Old Kangaroo Paddock'. Note the list of past and planned management events in the middle, and the list of predicted crop losses towards the bottom. Crop losses are coloured according to their severity. By clicking the buttons and events, or selecting from the menus at the top, the user can do things such as updating the simulation; generating more detailed graphical output; saving the current scenario; duplicating the scenario; adding, deleting or editing events; or reloading saved scenarios.



Figure 1. Screen shot of the Weed Seed Wizard interface.

Note that in this scenario, predicted crop losses are increasing over time, from 2.8% in 2001 to 28.8% in 2005. Part of the reason for this is that we have specified that the ryegrass is evolving resistance to Diclofop-methyl, and thus the applications of this herbicide in 2004 and 2005 are largely ineffectual. Note also that there is another tab labelled 'Old Kangaroo Paddock (high seeding rates)'. The management schedule and weather associated with this scenario is exactly the same as for the 'Old Kangaroo Paddock' scenario, except that higher seeding rates are used (200/m² vs 100/m² and 80/m² vs 40/m² for wheat and lupins respectively). The predicted crop losses for this second scenario are shown in Figure 2. Notice that in this scenario the losses decrease over time, even though the ryegrass is assumed to evolve resistance to Diclofop-methyl just as before.

In general, the results given by the Wizard confirm the pattern shown in this particular example: Maintaining an integrated approach to weed management that not only kills weeds, but also reduces seed set and prevents any set seed from entering the seedbank can effectively run down the weed seedbank. However, even a small lapse in the continuity of this effort can cause an increase in the seedbank that has a significant effect over several subsequent years.

Crop loss due to weeds in 2001: 3.3%
Crop loss due to weeds in 2002: 3.3%
Crop loss due to weeds in 2003: 2.8%
Crop loss due to weeds in 2004: 2.1%
Crop loss due to weeds in 2005: 1.8%

Figure 2. The list of predicted crop losses from the 'Old Kangaroo Paddock (high seeding rates)' scenario window.

CONCLUSION

The Weed Seed Wizard integrates current knowledge of weed biology and the effects of management techniques to simulate and predict annual weed populations. It is structured to allow emerging weed species, newly developed management options, and new discoveries to be easily added to the model. It allows us to explore how the dormancy, germination requirements, competitiveness, and herbicide resistance of different weed species or populations can affect the dynamics of the system, and thus the choice of an appropriate management strategy. Through incorporating the effects of herbicides and a range of other strategic options, the Wizard will help us design a truly integrated weed management system. By giving deeper insight into the how different factors interact to determine weed seedbank levels and helping farmers manage weeds within their paddocks, the Wizard will contribute to building the sustainability of Western Australian crop and pasture systems.

KEY WORDS

weed control, seed ecology, seedbank dynamics, simulation model, integrated weed management

ACKNOWLEDGMENTS

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Paper reviewed by: Fiona Evans, Art Diggle, Sally Peltzer

Frequency of herbicide resistance in wild oat (*Avena fatua*) across the Western Australian wheatbelt

Mechelle Owen and **Stephen Powles**, WA Herbicide Resistance Initiative, School of Plant Biology, University of Western Australia, 35 Stirling Hwy, Crawley WA 6009

KEY MESSAGES

- Widespread resistance to the Group A – ‘fop’ herbicides.
- Group A – ‘dim’ herbicides provide good control for wild oat.

AIMS

To identify the frequency and distribution of wild oat resistance to Group A herbicides in cropping paddocks from the Western Australian wheatbelt.

METHOD

Prior to harvest, during an eight week period (October-November 2005), a random seed collection survey was conducted across the WA wheatbelt to evaluate the level of herbicide resistance in wild oat. In total, 677 cropping paddocks from 15 agronomic zones were visited in the wheatbelt of WA. Within each zone, at least 30 paddocks were sampled at random, stopping at 5 km intervals to sample the nearest crop paddock (interspersed pasture fields were not sampled). Paddocks were surveyed by walking in an inverted ‘v’ pattern 200 m into the crop and collecting mature seed heads from wild oat plants in the sampling path. Wild oats were present in 291 of the paddocks, but were only collected from 150 fields (in 141 paddocks, less than 10 plants were found, with insufficient seed to constitute a representative sample). The seeds were then used in an extensive herbicide resistance screening study in 2006.

During the 2006 growing season, wild oat populations were germinated and 50 plants from each population were screened to a number of Group-A herbicides (Hoegrass®, Sertin®, Achieve® and Axial®). All herbicide treatments were applied at the two- leaf stage. Plants that survived the application of Hoegrass® were then cut back and resprayed with Sertin® to detect target site resistance (as plants are not able to metabolise Sertin®). Herbicide treatments were applied at rates designed to clearly identify resistant individual plants and populations. Mortality was recorded 21 days after each treatment. Wild oat populations were classified as; ‘resistant’ if 20% or more of the population survived the herbicide, as ‘developing resistance’ if between 1-19% survival and ‘susceptible’ if all the plants died. In all experiments, known susceptible and resistant populations were included as controls.

RESULTS

Distribution patterns of wild oat

In 2005, of the 677 paddocks visited, 43% of the paddocks contained wild oat plants. Samples were collected from 22% of the paddocks (Table 1). In a previous survey (Owen *et al.*) wild oat density data was recorded at the time of sampling. The visual density data recorded during both surveys was similar, with the same proportion of paddocks containing wild oat plants. The pattern of wild oat infestations varied across the State according to location and rainfall. Over half of the populations (51%) collected in the survey came from the H3, M3, L3 zones (Figure 1), with a further 30% of populations coming from the northern regions. The southern areas, particularly the coastal areas had very low wild oat infestations.

Wheat was the dominant crop (62%) followed by barley (15%) and oat (8%). Nearly three-quarters (71%) of wild oat samples came from wheat crops with a further 20% coming from barley crops. Only a small proportion of oat and lupin crops contained wild oat, while no wild oat plants were found in canola and field pea crops.

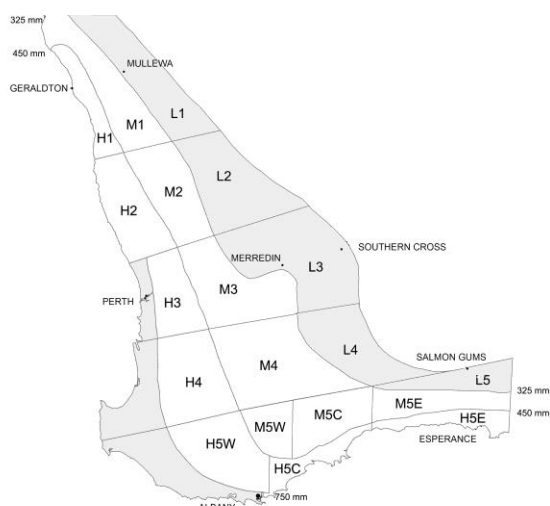


Figure 1. Map of Western Australian wheatbelt, showing the agronomic zones where samples were collected.

Table 1. The number of paddocks and percentage containing wild oat at each density classification

Density rating 2005	No. of paddocks	%
None no wild oats found	386	57
Very low (wild oat present but difficult to find)	141	21
Low (clearly present but less than 1 plant/m ²)	83	12
Medium (1-10 plants/m ²)	47	7
High (greater 10 plants/m ²)	15	2
Very high (crop 'swamped' by wild oat)	5	1
Total	677	100

Herbicide resistance

There were 150 wild oat populations screened with the Group-A herbicides, with high frequencies of resistance found to the Group-A herbicide diclofop-methyl (Hoegrass®). Just over three-quarters (77%) of these wild oat populations contained individual plants that were resistant to the 'fop' herbicides. Of these populations, 17% were classified as resistant with a further 60% developing resistance (Table 2). Of the populations resistant to Hoegrass®, 12 populations were classified as resistant to sethoxydim (Sertin®), and 12 populations (10%) were developing resistance.

Table 2. The number and (percentage) of resistant wild oat populations in each category for each herbicide. Populations classed as resistant (20% or more survival), populations classed as developing resistance (1-19% survival) and populations classed as susceptible if no plants survived

Herbicide	No. populations screened	Resistant	Developing resistance	Susceptible
Diclofop (fop)	150	24 (16%)	91 (61%)	35 (23%)
Sethoxydim (dim)	115	12 (10%)	12 (10%)	91 (80%)
Tralkoxydim (dim)	150	0	18 (12%)	132 (88%)
Pinoxaden (den)	147	2 (1.5%)	2 (1.5%)	143 (97%)

For the Group-A 'dim' herbicide Achieve® 18 populations (12%) were developing resistance. The 'den' herbicide Axial® had two populations classed as resistant and a further 2 populations developing resistance. Only 23% of populations were susceptible to all of the Group-A herbicides tested. More resistant populations tended to be associated with the medium and high rainfall zones, and the central zones (Table 3). Screening for resistance to the Group-B herbicide Hussar®, the Group-E herbicide Avadex® and the Group K herbicide Mataven® will continue in the 2007 growing season.

Table 3. The percentage of wild oat populations that are; resistant (R), developing resistance (DR) and susceptible (S) to each herbicide from each agronomic zone

Zone	No. Pop's tested	Hoegrass			Sertin			Achieve			Axial		
		R	DR	S	R	DR	S	R	DR	S	R	DR	S
H1	9	0	56	44	0	0	100	0	0	100	0	0	100
M1	8	0	12	88	0	0	100	0	0	100	0	0	100
L1	6	0	17	83	0	0	100	0	0	100	0	0	100
H2	2	50	50	0	0	50	50	0	50	50	0	0	100
M2	9	22	67	11	0	0	100	0	44	56	0	0	100
L2	11	9	64	27	12.5	12.5	75	0	0	100	0	0	100
H3	15	13	60	27	9	9	82	0	7	93	0	0	100
M3	22	36	46	18	28	11	61	0	14	86	5	10	85
L3	17	17.6	65	17.6	0	21	79	0	12	88	0	0	100
H4	12	17	83	0	0	25	75	0	17	83	0	0	100
M4	16	6	81	13	7	0	93	0	12	88	0	0	100
L4	4	25	75	0	0	0	100	0	0	100	0	0	100
H5	2	0	100	0	50	0	50	0	0	100	0	0	100
M5	13	23	69	8	25	8	67	0	23	77	8	0	92
L5	4	0	75	25	0	0	100	0	0	100	0	0	100

MANAGEMENT OPTIONS

There are a number of management options available to farmers that could be used to reduce the presence of wild oat in crop. By using an integrated weed management system, farmers can also reduce the risk of obtaining herbicide resistant wild oat populations. Some of the options available are:

- Herbicides – grass selective and spray-topping (with herbicide rotation).
- Cultural methods – delayed seeding, crop competition, cultivation, hay/silage, seed collection.
- Manage patches on a paddock basis.
- Prevent seeds returning to the soil (majority falls within 1 cm of its origin) – by mowing, grazing or spraying.
- Hygiene to prevent the spread of wild oat seed and minimise grain contamination.

CONCLUSION

There was widespread resistance to the Group A 'fop' herbicides; however resistance to the 'dim' herbicides was relatively low with less than 20% of populations having resistant plants, and less than 3% for the 'den' herbicide Axial®. Farmers can reduce the incidence of wild oat in their paddocks by managing the patches as the patches do not spread fast. This is because (1) they are self-pollinating (resistant plants are unlikely to cross with other plants around them); and (2) they shed early thus are less likely to be spread by the harvesting process. By reducing seed set during the spring (cut for hay, etc.), the number of potentially resistant seed being allowed back into the seed back can be reduced.

KEY WORDS

wild oat, herbicide resistance, random survey

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Paper reviewed by: David Minkey

Pollen mediated gene flow of herbicide resistance can occur over long distances for annual ryegrass (*Lolium rigidum*): Results of two years with different meteorological conditions

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KEY MESSAGES

Successful cross-pollination can occur between herbicide susceptible and herbicide resistant annual ryegrass plants at distance up to 3000 m due to pollen drift.

Pollen dispersal is prevalent in cross-pollinating species such as ryegrass and can be strongly influenced by meteorological conditions.

AIMS

- To study pollen mediated gene flow at long distance in annual ryegrass under field conditions.
- To demonstrate that herbicide resistance in annual ryegrass is highly mobile via pollen flow.
- To quantify resistance mobility and collect data in real commercial conditions for future development of models.

METHOD

Gene flow studies were conducted during the spring periods of 2005 and 2006. In both years, before anthesis, individual ryegrass plants (*Lolium rigidum*) were placed in an undisturbed, ryegrass-free bushland area where no ryegrass plants exist near Salmon Gums (Western Australia). *L. rigidum* is an anemophilous self-incompatible weed species and seed can only be produced by cross-pollination. In 2005, 85 plants of a known herbicide susceptible ryegrass population (VLR1) were used and in 2006 the experiment was repeated with 109 ryegrass plants. Single susceptible plants were arranged at varying distances (0 to 4000 meters) from wheat and pasture fields (pollen donor source) known to be infested with herbicide resistant annual ryegrass plants. At plant maturity the susceptible plants were harvested. After threshing seed was collected and weighed to estimate the number of seeds from each single plant. Samples of resident ryegrass populations (100 plant spikes) were also collected from 37 locations across the pasture and crop areas. These samples were tested for resistance to ALS inhibitors and the experiment was conducted in pots outdoors during May-August 2006. Plants were sprayed with 15 g ha⁻¹ of sulfometuron to assess the level of resistance in the experimental area (i.e. phenotypic resistance frequency). Plant survival was recorded three weeks after spraying and the resistance frequency was calculated as the percentage of surviving plants. To test whether cross pollination resulted in resistance gene movement, seedlings grown from the seed produced on susceptible mother plants were screened with the same rate of sulfometuron (15 g ha⁻¹). Previous bioassays carried out on this susceptible population (VLR1) had shown no survival at 10 g ha⁻¹ of sulfometuron.

RESULTS

2005

The average frequency of resistance (i.e. proportion of plant survival to sulfometuron) in the resident populations was 50% (Figure 1). This represents the extent of herbicide resistance throughout the experimental area. In total, 3071 seeds obtained from the herbicide-susceptible plants were screened for resistance to the ALS herbicide sulfometuron giving a resistance frequency on average of 24% (Figure 1).

From 51 of the herbicide susceptible mother plants 26131 seeds were obtained, suggesting pollen successfully moved with wind and caused cross pollination up to 3000 meters from its source (Figure 2). Some plants were either eaten by herbivores or died from drought stress. Seeds produced on herbicide susceptible mother plants must be herbicide susceptible unless they were pollinated by pollen carrying resistant genes from plants in the wheat/pasture fields. Herbicide resistance was found at a distance of 3000 meters from the resistance source (paddocks infested with resistant ryegrass). Both the amount of seed production and herbicide resistance followed a leptokurtic distribution according to the distance from the resistant pollen source (Figure 2).

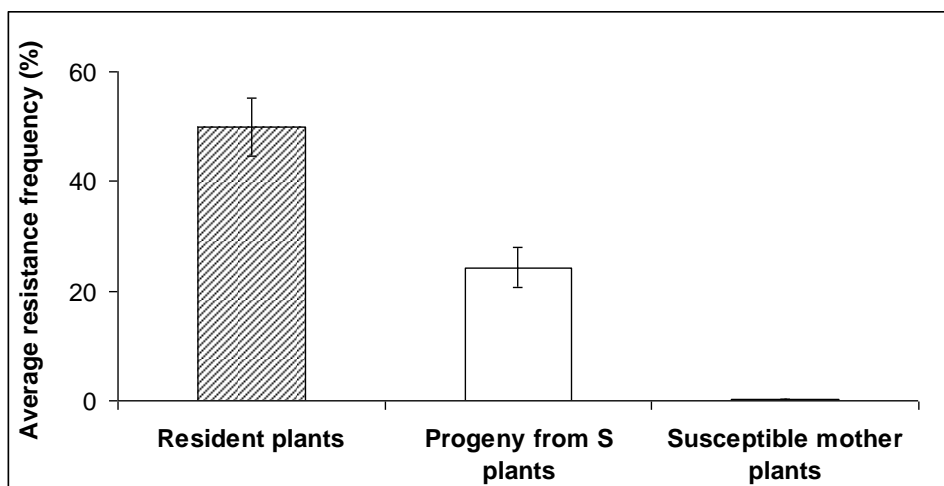


Figure 1. Average resistance frequency observed in the resident population, the progeny of susceptible mother plants and the susceptible mother population (VLR1).

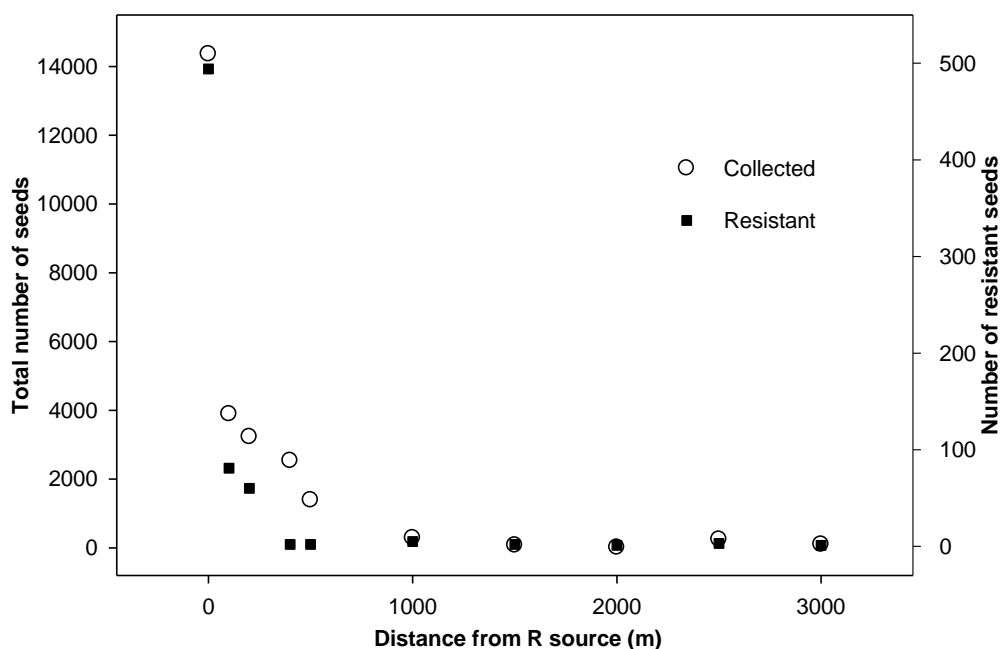


Figure 2. Total number of collected and resistant seeds in relation to distance from the pollen donor source in 2005.

2006

In 2006 the adverse meteorological conditions strongly affected the results. Rainfall during the growing season was much lower compared to 2005 (Figure 3). During anthesis (from September to December) the difference was even more significant (the cumulative rainfall in 2005 was 100 mm compared to 31 mm in 2006). Throughout the season the relative humidity in 2006 was lower than in 2005 (data not shown). Seed production on VLR1 plants was very low. Only three seeds were recovered after threshing from three individual plants (Figure 4). The high majority of plants produced sterile spikes and florets with an average dry weight of 0.7 g.

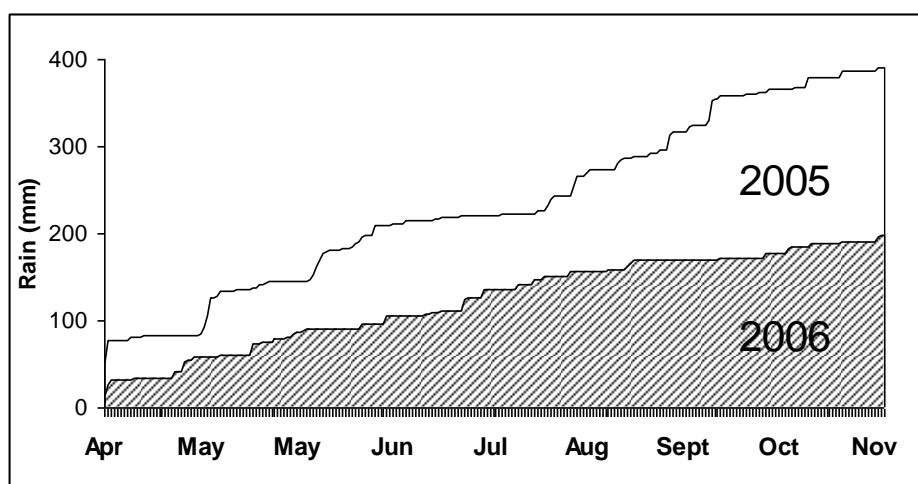


Figure 3. Cumulative rainfall in 2005 and 2006 growing season in Salmon Gums.

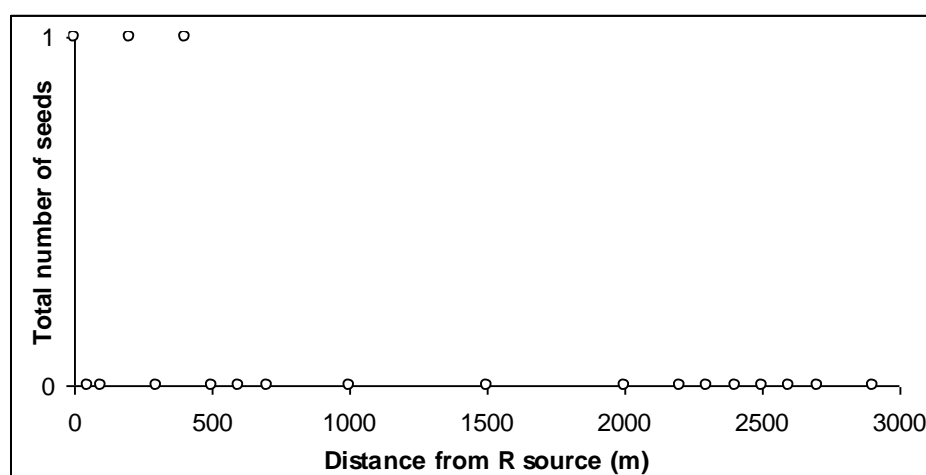


Figure 4. Total number of collected seeds in relation to distance from the pollen donor source in 2006.

CONCLUSION

Our results establish that resistance gene flow due to effective cross pollination occurred by natural movement of resistant pollen over distances up to 3000 m. In 2005 a lower frequency of resistance was observed in the progeny of susceptible VLR1. The expected value of resistance frequency in the progeny of the susceptible mother plants should be equivalent to the resistance frequency in the donor resident plants (i.e. 50%). A lower resistance frequency in the progeny could be due to the presence of heterozygous individuals in the donor plants or to the heterozygous status of resistance endowed by a semi-dominant gene. Also some pollination among susceptible plants cannot be excluded in 2005.

The results obtained in the field experiment in 2006 are difficult to interpret. Firstly, the 2006 season was characterised by severe meteorological conditions for pollen movement and viability which hampered almost completely cross-pollination. The already poor development and low density of ryegrass plants in pastures was kept extremely low by grazing sheep. Also the low rainfall caused a shorter growing season compared to 2005 and this probably resulted in scarce overlapping of flowering periods between the resident populations and VLR1 plants. The results suggest that cross-pollination among susceptible mother plants was not likely.

Our results show long distance herbicide resistance mobility by pollen drift is a real concern for cross-pollinated species such as *L. rigidum*. This is the first report of herbicide resistance gene flow by pollen in ryegrass at long distances. The results of this study are consistent with the modelling simulations performed by Giddings (2000) on pollen dispersal in *L. perenne*. This study also confirms a WA farmers' perception that herbicide resistance can move among farm enterprises. Long distance

resistance gene flow in commercial field conditions is critical to understanding the dynamics of resistance dispersion. The field experiment will be repeated in 2007. However this study needs to be complemented by data on pollen competition in ryegrass to provide an important contribution in understanding and modelling the evolution of herbicide resistance and gene flow at the landscape level. Prevention and management of herbicide resistance should not be discarded by farmers even if the potential of resistance mobility by pollen is high. Since herbicide resistance is highly mobile by pollen, especially in those years with optimal meteorological conditions (i.e. high rainfall), a strategic plan is required to minimise pollen production, dispersal and cross-pollination in ryegrass.

KEY WORDS

gene flow; pollen dispersal; herbicide resistance; *Lolium rigidum*

ACKNOWLEDGMENTS

The authors are thankful to the Grains Research & Development Corporation (GRDC) for the funding provided to the Western Australian Herbicide Resistance Initiative (WAHRI) a major strategic initiative established in 1997. A special thank to the Guest family for support provided.

Paper reviewed by: Michael Walsh

Doublegee has developed resistance to metsulfuron-methyl within WA wheatbelt

Dr Abul Hashem¹ and Dr Shahab Pathan², ¹Senior Research Officer, Northam and ²Research Officer, Merredin Department Agriculture and Food, Western Australia

KEY MESSAGES

One case of metsulfuron-methyl-resistance in doublegee (population DG1) has been confirmed within the northern agricultural zone of WA wheatbelt. This population is five times more resistant to metsulfuron-methyl than the known susceptible population of doublegee. This metsulfuron-methyl-resistant population is susceptible to all the group C herbicides (e.g. atrazine, bromoxynil, cyanazine, diuron, metribuzin, and simazine) tested in this study.

AIMS

The aim of this study was to confirm the development of herbicide resistance in two doublegee populations to Group B herbicides (ALS-inhibitors).

METHOD

During the spring of 1999 metsulfuron-methyl (e.g. Ally[®]) failed to control two doublegee populations in the northern WA wheatbelt. Seed was collected from the survivors within these populations and submitted for testing (Population DG1 and Population DG2). In 2000, an initial herbicide resistance screening (Experiment 1) was conducted on DG1, DG2 and a known susceptible population (DG3) collected from the Merredin Research Station (Table 1). Progeny 1 seed from the plants surviving various herbicide treatments in Experiment 1 was collected in 2000. A dose response curve test (Experiment 2) was conducted in 2001 on the Progeny 1 of these three populations with metsulfuron-methyl and metribuzin but surviving plants in experiment 2 were damaged pre-maturely by unidentified pests. Progeny 1 seeds were multiplied in pots maintained outdoors in 2003 and dose response curve test (Experiment 3) was again conducted on metsulfuron-methyl and metribuzin at Merredin in 2005.

RESULTS

Experiment 1 and 2

Initial herbicide resistance screening test in experiment 1 showed that 47, 84 and 100% of doublegee plants of population DG1 and 33, 11 and 96% of population DG2 survived metribuzin, triasulfuron and imazethapyr respectively (Table 1). Both populations were completely controlled by atrazine, bromoxynil, cyanazine, diuron, and simazine in experiment 1. Although the doublegee plants in experiment 2 were defoliated by unidentified pests, survival of the treated plants indicated that population DG2 was likely to be resistant to metsulfuron-methyl (result not shown).

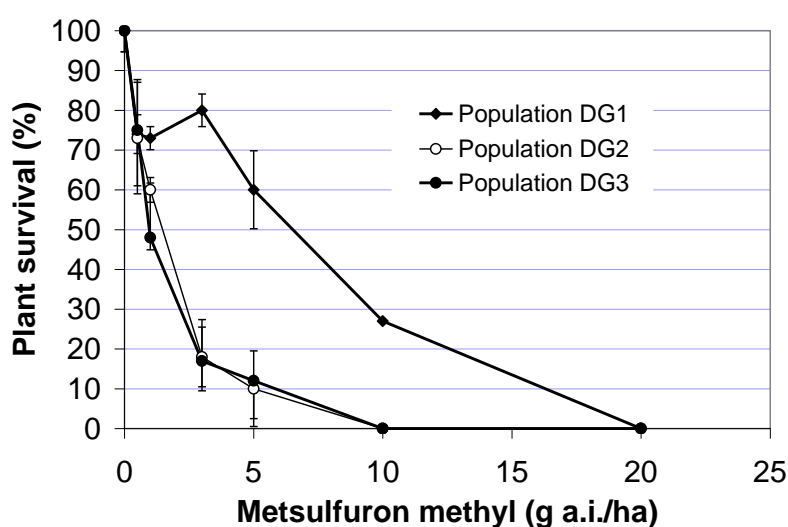
Experiment 3

Resistance to metsulfuron-methyl. Exposure of doublegee plants to 3 g a.i./ha of metsulfuron-methyl at 3-4-leaf stage, controlled more than 80% of plants from populations DG2 and DG3 but only 20% of plants from DG1 (Figure 1). Increasing the rate of metsulfuron-methyl to 5 g a.i./ha controlled nearly 90% of populations DG2 and DG3 but only 40% of DG1. At 10 g a.i./ha of metsulfuron-methyl, all plants from populations DG2 and DG3 died but 27% population DG1 survived even at this rate. The label rate of metsulfuron-methyl for doublegee is 3.75 g a.i./ha. LD₅₀ ratio showed that population DG1 was five times more resistant to metsulfuron-methyl than the known susceptible population DG3.

Resistance to metribuzin. The label rate of metribuzin is 150 g a.i./ha for Eagle Rock wheat and 135-285 g a.i./ha for field pea. Dose response curve test (experiment 3) showed that 100 g a.i./ha of metribuzin controlled about 80% of populations DG2 and DG3 but 200 g a.i./ha controlled 86% of DG1 and DG2 and 95% of DG3 (data not shown). Although 8% of population DG1 survived even at 800 g a.i./ha of metribuzin, the LD₅₀ ratio (1.3) did not indicate a significant resistance in this population compared to DG2 or DG3. Therefore, population DG1 was not resistant to metribuzin.

Table 1. Effect of commonly used herbicides at or near label rate on the survival of doublegee seedlings in Experiment 1 under glasshouse conditions at Merredin in 2000

Herbicides	Population DG1		Population DG2	
	Seedling survival (%)	SE	Seedling survival (%)	SE
Simazine 500 g a.i./ha PS	0	0.0	0	0.0
Atrazine 1 kg a.i./ha + 1% Uptake PO	0	0.0	0	0.0
Diuron 1 kg a.i./ha PSPE	0	0.0	0	0.0
Metribuzin 150 g a.i./ha PSPE	47	57.7	33	12.2
Triasulfuron 23 g a.i./ha PS	84	19.2	11	8.7
Imazethapyr 40 g a.i./ha PSPE	100	0.0	96	7.2
Cyanazine 1 kg a.i./ha PS	0	0.0	0	0.0
Bromoxynil 200 g a.i./ha PO	0	0.0	0	0.0
Untreated	100	0.0	100	0.0

**Figure 1. Doublegee plant survival at various rates of metsulfuron-methyl under glasshouse conditions.**

CONCLUSION

The results on the dose response curve test have clearly shown that doublegee population DG1 has developed resistance to metsulfuron-methyl within the WA wheatbelt. More research is necessary to confirm the resistance of this population to other Group B herbicides such as triasulfuron and imazethapyr. The metsulfuron-methyl-resistant doublegee population DG1 can be effectively controlled by all the Group C herbicides used in this study.

KEY WORDS

doublegee resistance, metsulfuron methyl, Group C herbicides, WA wheatbelt

ACKNOWLEDGMENTS

We are grateful to GRDC for funding. Special thanks to Nerys Wilkins for excellent assistance.

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Paper reviewed by: Dave Minkey and Vanessa Stewart

Another case of glyphosate resistance in annual ryegrass confirmed within Western Australia

Dr Abul Hashem¹ and Dr Shahab Pathan², ¹Senior Research Officer, Northam and ²Research Officer, Merredin, Department Agriculture and Food, Western Australia

KEY MESSAGES

- A fifth case of glyphosate resistance in Western Australia has been confirmed in the KM population of annual ryegrass. This population of annual ryegrass is 11.4 times more resistant than the glyphosate-susceptible population.
- Annual ryegrass biotypes with glyphosate resistance gene like this are likely to be present elsewhere within WA wheatbelt. Growers should minimise risks of glyphosate resistance in annual ryegrass by adopting the practices such as double knockdown, strategic full-cut sowing, strategic cultural weed control and effective in-crop chemical weed control.

AIMS

The aim of this study was to confirm yet another case of glyphosate resistance in annual ryegrass within Western Australia.

METHOD

Following the control failure of annual ryegrass in 2002, 2003 and 2004 seasons by glyphosate even at 1.5 kg a.i./ha in a 2-hectare vineyard in the Toodyay area of Western Australia, surviving annual ryegrass plants were collected at heading stage in September 2004 and named KM population. Plants of KM population were transplanted in 10 L pots filled with potting mix and composts, maintained outdoors and mature seeds were collected in November 2004. In 2005, a glyphosate dose response test was conducted on this suspect glyphosate-resistant KM population along with a known glyphosate-susceptible population (Safeguard) under glasshouse conditions at Merredin. Glyphosate was sprayed at 3-4-leaf stage of annual ryegrass plants and plant survival was assessed three weeks after spraying.

RESULTS

Confirming glyphosate resistance in the KM population

All the plants (100%) of KM population of annual ryegrass survived at 270 g a.i./ha glyphosate compared to only 16% of the Safeguard population at this rate (Figure 1). At 540 g a.i./ha of glyphosate, 97% of KM population survived while all the plants of the Safeguard population died at this rate. Seventy nine per cent of the KM population survived at 1080 g a.i./ha glyphosate and 33% survived even at 2160 g a.i./ha which is nearly a six times stronger rate than the label rate used to control annual ryegrass at pre-tillering stage. LD₅₀ ratio of the R to S population showed that the KM population was 11.4 times more resistant than the susceptible Safeguard population. This is the fifth confirmed case of glyphosate resistance in annual ryegrass within WA wheatbelt.

National glyphosate resistance management strategies

In Australia, 55 annual ryegrass populations with confirmed resistance to glyphosate have been reported since the discovery of the first population in 1996. Intensive glyphosate use and lack of tillage targeting annual ryegrass have been found to be two of the key predisposing factors for glyphosate resistance in broadacre cropping. The national Glyphosate Sustainability Working Group (GSWG) has established a series of on-line resources to help growers and advisors keep abreast of glyphosate resistance (website: www.weeds.crc.org.au/glyphosate). Supported by Croplife Australia, the CRC for Australian Weed Management and the GRDC, the Group brings together glyphosate experience from Monsanto, Syngenta, Nufarm, WA Herbicide Resistance Initiative (University of WA), University of Adelaide, Charles Sturt University, Queensland DPI&F, Department of Agriculture and Food, WA, NSW DPI, CRT/Town & Country, and GRDC.

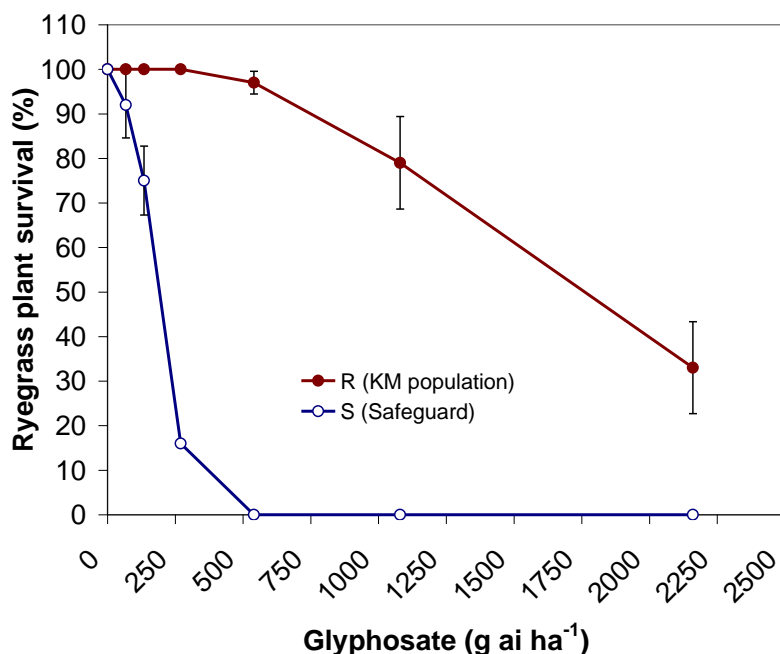


Figure 1. Survival of resistant (R) KM population of annual ryegrass at various rates of glyphosate compared to susceptible (S) Safeguard population under glasshouse conditions.

This collaborative initiative aims to promote the sustainable use of glyphosate in Australian farming. A key output from the GSWG is the 'Keep Glyphosate Resistance Rare' guide. This guide details practices that increase or decrease the risk of developing glyphosate resistance in annual ryegrass.

Practices that increase glyphosate resistance risks. Continuous reliance on pre-seeding glyphosate knockdown, lack of tillage, lack of effective in-crop weed control, inter-row glyphosate use (unregistered), frequent glyphosate-based chemical fallow, frequent croptopping with glyphosate, and high weed numbers.

Practices that decrease glyphosate resistance risks. The double knock technique, strategic use of alternative knockdown groups, strategic full-cut cultivation, effective in-crop weed control, use alternative herbicide groups or tillage for inter-row and fallow, non-herbicide practices for weed seed kill, croptopping with alternative herbicide groups, and use of strategic cultural weed control.

CONCLUSION

A fifth case of strong glyphosate resistance in annual ryegrass has been confirmed in a 2 ha vineyard within WA wheatbelt. It is suspected that this population may have already spread into the adjacent 5 ha of grain cropping area belonging to the same grower.

Although this highly-resistant population came from vineyard, annual ryegrass biotypes with glyphosate resistance gene like this is likely to be present elsewhere within WA wheatbelt and can be selected if integrated weed management options are not fully adopted. This has already happened in the Eastern States such as NSW, SA and Victoria, and can happen here in WA. At least five more annual ryegrass populations that are suspect of glyphosate resistance are now under study at the Department of Agriculture and Food, Western Australia. Three of these five populations were collected from grain cropping areas.

Case studies in NSW showed that glyphosate-resistance developed in annual ryegrass within winter chemical fallow area after 20 years with up to eight applications of glyphosate per year (see Andrew Storrie's paper in this book). Given the current trend in the increase of glyphosate-resistance cases in Australia, in five years time many more glyphosate-resistant annual ryegrass populations are likely to be documented in WA as already occurred in the Eastern States. If GM crops with resistance to glyphosate are ever introduced into WA, the glyphosate resistance situation is likely to be even worse than without GM crops. The parallel already exists in the US with widespread glyphosate resistance from repeated use in Roundup Ready® corn and soybeans.

It is, therefore, extremely important that growers adopt integrated weed management options and follow the glyphosate management strategies already developed by GSWG. Otherwise, widespread development of glyphosate-resistance in annual ryegrass will have serious impact on no-till seeding systems, crop topping, wide row cropping systems, and pasture manipulations. The consequence is that productivity of WA wheatbelt land will be seriously reduced.

Growers should minimise risks of glyphosate resistance development in annual ryegrass by adopting the practices such as double knockdown, strategic full-cut sowing, strategic cultural weed control and effective in-crop chemical weed control.

KEY WORDS

Glyphosate resistance, annual ryegrass, national glyphosate resistance management strategies, integrated weed management

ACKNOWLEDGMENTS

We are grateful to GRDC for funding. Special thanks are due to Nerys Wilkins and Chris Roberts for technical help. Information on glyphosate resistance management strategies has been drawn from GSWG website: www.weeds.crc.org.au/glyphosate.

Project No.: DAW00114

Paper reviewed by: Mr Andrew Storrie and Dr David Bowran

Glyphosate resistance in the northern NSW – implications for Western Australian farming systems

Andrew Storrie, Tamworth Agricultural Institute, NSW Department of Primary Industries, 4 Marsden Park Rd, Calala NSW 2340

KEY MESSAGES

- Herbicide resistance will develop in ANY farming system reliant on herbicides for weed control.
- Chemical fallows are highly susceptible to the development of glyphosate resistance.
- NSW-Qld Northern grain region experience shows if global warming increases summer rainfall in the Western Australian wheatbelt farmers will face the same herbicide resistance risks.
- Species with a high risk of developing glyphosate resistance include any annual grass, sowthistle and fleabane.
- Glyphosate resistance in winter cropping systems is likely to spread into the paddock from fence lines, chemical firebreaks and contaminated seed.
- All farmers must introduce a broad range of integrated weed management tactics to manage glyphosate resistance.

GLYPHOSATE RESISTANCE IN EASTERN STATES

Currently in Australia annual ryegrass (ARG) remains the only species with populations resistant to glyphosate. The first case of glyphosate resistance in the world was found in ARG in 1996 at Echuca in an irrigated no-till wheat paddock. The following year glyphosate resistant ARG was found in an orchard at Orange, NSW. The next big find was in 1999 on the southern Liverpool Plains, south west of Tamworth, NSW, where resistant ARG plants were found in a paddock of wheat stubble. In 2000, another population was identified 250 km to the northwest in another chemical fallow.

Since then more populations have been identified, primarily in orchards and vineyards, irrigation channels, fence lines and chemical firebreaks. The current official population count is; NSW – 30; South Australia – 17; Victoria – 3; WA – 5.

Northern NSW has 18 confirmed cases of glyphosate resistance in ARG in chemical fallow, however a 'road survey' in December 2006 showed that 60 per cent of paddocks on the southern Liverpool Plains had ARG plants that had obviously survived at least one glyphosate application. Most farmers in this area assume that if they have ARG, it is resistant to glyphosate. Infestations range from a few plants to paddocks covered by ARG. A 'new' infestation was found in 2006 between Narrabri and Moree, which is a new area to previous infestations.

NORTHERN FARMING SYSTEMS – A SPECIAL CASE?

So what makes the northern farming system so special that there are so many paddocks with glyphosate resistant ARG?

Topography and climate

The southern Liverpool Plains has an average annual rainfall of 650 mm with 60% falling in summer. High intensity summer storms are the norm in the northern grain region. This combined with stony hills leads to highly eroding flash flooding down the sloping highly erodable (vertisol) soils. Many intermittent creeks run down from the hills and the land is divided by roads, grassed waterways, stock-routes and fencelines. The soil types are predominately self mulching and non self-mulching heavy clays with neutral to alkaline pH.

Most of this land was not cropped until the 1970s due to the difficulty in storing sufficient soil moisture in the deep clay soils and most cropping was conducted on the lighter red loams. Ryegrass was always present in the grazing (hill) country but was never been an important weed of these heavier soils.

Agricultural system

The NSW-Qld northern grain region, and the Liverpool Plains in particular, have a high adoption of no-till amongst the better farmers with some farmers no-tilling since 1980. Reduced cultivation/no-till allows stubble retention to reduce the risk of water erosion and allows the storage soil moisture. Cultivation usually gives a lower yield compared with no-till on these soil types.

Reduced tillage systems are possible through the extensive use of glyphosate to control fallow weeds. Every hectare receives an average of four glyphosate applications per year, with up to eight in a wet year. In summer, fallow paddocks are sprayed with glyphosate every six weeks, even with no rain. Glyphosate is normally applied without a tank mix partner, with rates creeping up over the years. The average application rate is now 1.8-2.0 L/ha. Group B chemistry has not been used in areas growing summer crops due to the persistence of residues from sulfonylureas in the alkaline soils. There has also been a reduction in the use of atrazine in winter fallows before sorghum due to potential groundwater contamination issues. Early atrazine applications were discontinued in winter fallow leading to ineffective control of larger ARG in early spring.

Winter and summer crops are grown in rotation with wheat still the main winter crop and sorghum the main summer crop. A typical crop sequence would be wheat-sorghum-fallow giving two crops in three years or wheat-alternative winter crop-sorghum-fallow giving three crops in four years. Fallows of 6-14 months are used to store subsoil moisture, with planting possible when one metre of soil moisture is stored. High yields make these long fallows profitable. Wheat yields range from 4 to 6 t/ha while sorghum yields from 7 to 10 t/ha. Winter cereals are usually sown on 37 cm rows, while pulses and sorghum are grown on 50 to 100 cm rows. Stock (cattle) tend to be confined to red ridges and most fences have been pulled in the no-till country.

These long fallows create the opportunity for ARG, and other species, to grow with little competition in fallows while the wide crop row spacing also reduces crop competition. Canopy closure in wheat may not occur for 12-14 weeks after crop emergence. Twenty years ago, ARG was never a problem in winter crops, and the main focus of annual winter grass weed control was wild oats. Most in-crop wild oat herbicides were not effective on ARG.

How have the farmers responded to the situation?

Slowly is the first word that comes to mind. Glyphosate resistant ARG usually first appears as a few isolated plants, either in the paddock or along a fenceline. Some farmers will pull these out or spray with clethodim by boom. If the patch is dense or plants large, a few will survive and set seed. Most farmers don't see the urgency about preventing seed set of this plant. They have many competing interests for their thoughts and time and farm labour is also at a minimum. The advisers are busy explaining to farmers the need for the introduction of some integrated weed management (IWM) and the necessity of using paraquat or Spray.seed® on small seedlings. Advisers encourage their clients to spray fallow pre-plant with clethodim + chlorsulfuron/triasulfuron, then follow in-crop with iodosulfuron. The farmer is then unhappy with the rising cost of weed control. Unfortunately some farmers sow the winter crop with live ARG plants present, which usually make it through the season unscathed, setting large quantities of seed. Mild winters confound the problem with impressive weed growth rates.

Farmers who have dealt with large populations of resistant ARG have introduced paraquat/Spray.seed® pre-sowing and as a spray-topping application in fallow. A few farmers have purchased Weedseeker® units (infra-red reflectance trigger) to spray fallows in spring with clethodim or a bipyridal in an effort to keep herbicide costs down.

Resistance to other modes-of-action

December 2006 saw the first clethodim + glyphosate resistant ARG. Growers and agronomists jumped for the clethodim fix six years ago (permit pending), following a trial that showed excellent control of glyphosate resistant ARG. This will increase the pressure on farmers to adopt non-herbicide IWM practices.

WHAT COULD FARMERS CHANGE TO REDUCE THE GLYPHOSATE RESISTANCE THREAT?

- Better timing of paraquat and Spray.seed® in fallows, targeting the main weed flushes.
- Cultivate the main flush of weeds. Not possible in wet seasons.
- Use double knock – glyphosate followed by paraquat or Spray.Seed®.
- Introduce residual herbicides into the fallow phase.
- Sow winter crops on narrow row spacing (might need stubble burning or mulching).
- Increase sowing rates.
- Windrow crops.
- Early harvest and burn stubble rows.
- Grow herbicide tolerant crops.

WHAT ARE THE FUTURE GLYPHOSATE RESISTANCE CANDIDATES?

As part of the Northern Herbicide resistance project, a risk assessment was conducted on northern weeds to determine their likelihood of developing resistance. Those calculated as a high risk to developing glyphosate resistance are presented in Table 1.

Table 1. Northern weeds assessed as high risk for developing glyphosate resistant populations

Weed	Northern NSW	Southern Qld
Wild oats (<i>Avena</i> spp.)	✓	
Sowthistle (<i>Sonchus</i> spp.)	✓	✓
Black bindweed (<i>Fallopia convolvulus</i>)	✓	✓
Mustard / turnip	✓	
Fleabane (<i>Conyza</i> spp.)	✓	✓
Barnyard grass (<i>Echinochloa</i> spp.)	✓	✓
Liverseed grass (<i>Urochloa panicoides</i>)	✓	✓

The factors that all these weeds have in common are:

- Annuals that produce large quantities of seed giving large seedling populations.
- History of herbicide resistance somewhere in the world.
- Exposed to a lot of herbicide in the farming system.

Barnyard grass

At the time of writing, there are three properties with suspected glyphosate-resistant awnless barnyard grass (*Echinochloa colona*) populations which are to be tested. If confirmed this will be another world first for Australia!

Common factors between these properties include a long history of winter cropping with summer fallow control entirely with glyphosate, high incidence of summer storms and lighter textured soil favouring establishment of large barnyard grass populations.

Fleabane

In northern NSW and southern Queensland fleabane has become a major weed of summer fallows, winter pulses, roadsides and fence lines. In the summer of 2005-06 the northern herbicide resistance team surveyed fleabane populations for identification and collected seed for testing susceptibility to

glyphosate. In NSW 43 specimens were flax-leaf fleabane and 3 tall fleabane, while in Queensland 35 populations were flax-leaf fleabane and 6 tall fleabane. No Canadian fleabane specimens were collected.

Preliminary results from the glyphosate screening shows large differences in susceptibility between fleabane populations, which may be linked to previous exposure to glyphosate.

CONCLUSION

Farming systems reliant on glyphosate for fallow weed control will lead to the development of resistant weeds if survivors are not controlled and prevented from setting seed. This will require an increase in paddock monitoring and record keeping.

Originally it was thought that summer cropping systems in the northern grain region would buffer against the development of resistance due to the wide range of crops and opportunities for using a wider range of weed management tactics. History has shown the opposite to be true because farmers were (are) maintaining simple cost-effective weed control by relying on herbicides. Farmers in the higher rainfall areas east of the Newell Highway have many opportunities and the cash flow to enable implementation of other, sometimes less profitable tactics. The lower rainfall areas of the northern region with summer dominant rainfall pose some major weed management issues. Summer cropping in this area requires a higher level of management and better soil types, yields and returns are lower and herbicides are heavily relied upon. Herbicide resistance is set to explode in a number of weed species and modes-of-action. The sharing of seed for sowing is common and an excellent way to introduce new resistant weeds.

Development of glyphosate resistance in no-till winter cropping systems is most likely in summer weeds. If global warming increases the incidence of summer rain in the Western Australian wheatbelt the risk of glyphosate resistance, or species shift, in summer weeds will increase exponentially.

The real threat for winter weeds developing resistance will come from ingress from fence lines, roadsides, irrigation channels and chemical firebreaks. The GSWG register shows that these areas are most likely to develop glyphosate resistance in southern Australia. Abul Hashem and Shahab Pathan's paper at this Update supports this view.

KEY WORDS

glyphosate resistance, annual ryegrass, fleabane, barnyard grass

ACKNOWLEDGMENTS

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Paper reviewed by: Sally Peltzer, Abul Hashem

Alternative pre-emergent herbicides to trifluralin for annual ryegrass control

Mr David Minkey* and **Dr Abul Hashem****, Department of Agriculture and Food, Western Australia. *University of Western Australia, Crawley; **Northam District Office, Northam

KEY MESSAGES

- Trifluralin resistance has hit Western Australia.
- Several alternative herbicides and mixtures have been identified as alternatives to trifluralin.
- Care must be taken to preserve these herbicides and avoid the development of resistance.

INTRODUCTION/METHODS

Three populations of annual ryegrass in Western Australia have now been confirmed resistant to trifluralin. Furthermore, in a random survey throughout the wheat belt, carried out by the Western Australian Herbicide Resistance Initiative, 24% of all plants tested showed low level of resistance (1-20% survival). In some areas of South Australia where the use rates of Trifluralin have historically been much higher than in WA up to 50% of all annual ryegrass populations have been shown to be resistant to this herbicide. Finding an alternative residual herbicide to replace trifluralin is therefore essential.

The following is a summary of three years field work in the Western Australian wheat belt that included sites at Merredin, Meckering, Avondale, Wongan Hills, Newdegate and Mt Barker. Unless otherwise stated all herbicides were applied immediately before sowing and incorporated with the seeding process using a tined machine with knife points and press wheels.

THE HERBICIDES

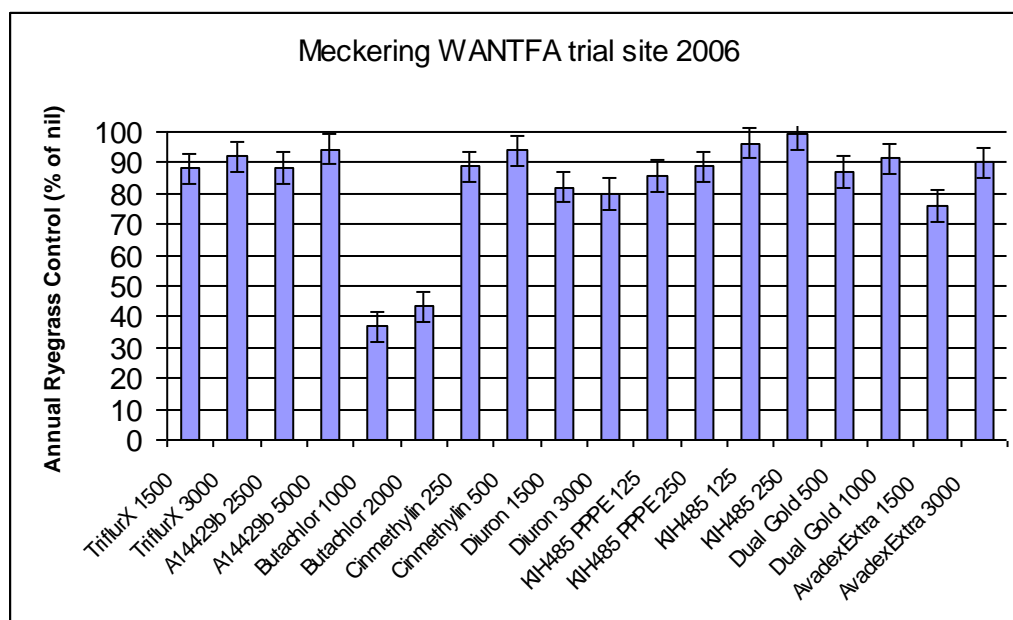


Figure 1. Performance of residual herbicides on annual ryegrass efficacy at Meckering in 2006. Figures after the herbicide name represent the dose in mL/ha.

Apart from Butachlor all herbicides examined performed well (Figure 1). This was consistent across all years and most sites and so the Meckering data set represents a typical response of these herbicides to annual ryegrass control in the Western Australian Wheat Belt. The exceptions to this

were at Newdegate in 2006 which had a trifluralin resistant population of annual ryegrass where the trifluralin treatments were ineffective, including mixtures at low doses, and at Mt Barker in 2006 where a massive weed burden occurred and multiple germination events masked the herbicide response. However, KIH 485 (see below) performed particularly well at the Mt Barker site indicating that this herbicide may persist in the soil longer than the others tested here.

A14429b

A14429b will be released in 2008 as 'Boxer Gold' by Syngenta. Field results showed excellent control of annual ryegrass at the 2.5 L/ha rate (cost unknown), equivalent to trifluralin (1.5 L/ha) in all trials, and at one site suppressed high populations of barley grass. Suppression of brome grass has also been reported. Boxer Gold will be a more flexible herbicide than trifluralin as it is a less volatile product. Crop safety in wheat has been excellent with only some observable damage at the 5 L/ha rate (double recommended rate). Future work will tell us of its potential in Zero till disc seeding systems. It is more soluble than trifluralin and so efficacy has the potential to be higher in the presence of stubble depending on spray water volumes, nozzle types and rainfall events.

KIH485

KIH485 is a new herbicide from Kumiai which is currently targeted for release in the USA in 2010 (corn and soybean market). The mode of action is not yet fully understood and is currently under investigation. Glasshouse and field trials have demonstrated that it is very safe in wheat, even when applied directly to the seed, and there is some evidence that it is safe in lupin and oats. In the field (125 g/ha, cost unknown) it out performed trifluralin (3 L/ha) in control of annual ryegrass and gave excellent control of barley grass at one site (WANTFA, Meckering trial site). It can be applied post sowing, pre emergent although efficacy falls off slightly compared to being applied immediately before sowing. KIH485 out performed all other treatments used in 2006 (KIH-485 has only been trialled in WA this year). There are many more years of testing before this, possibly, becomes available and future work will examine its weed spectrum and performance in zero tillage disc seeding systems.

Cinmethylin

Cinmethylin or Argold (also known as Cinch) is a group K herbicide. While its mode of action is unknown it has been shown to inhibit asparagine synthetase and is different from other group K herbicides such as Metalachlor. Performance of Cinmethylin on annual ryegrass efficacy has generally been good at around the 250 mL/ha rate (cost unknown) but at the 125 mL/ha rate mixed results have been found and is possibly related to inadequate soil moisture. Some crop damage has occurred in past research on sandy soils in wet conditions.

S-Metalachlor

S-Metalachlor or Dual Gold is another group K herbicide that performed well on annual ryegrass at the 500 mL/ha rate (\$14.30). Crop phytotoxicity in wheat is a concern at this rate and has more use at a lower dose in a mix with other herbicides – see below. S Metolachlor is only registered up to 250 mL/ha in wheat and at this rate gives poor ryegrass control. Boxer Gold is designed to replace Dual Gold for use in wheat.

Avadex Xtra

Avadex (Triallate) is a group E herbicide and is known as a wild oat herbicide. It controls annual ryegrass at the 3 L/ha rate (\$38/ha). While this is cost prohibitive it does offer a different mode of action. It performs well when mixed with other herbicides. Avadex has a fast (within six hours) incorporation requirement which restricts this herbicide to be used in Zero tillage disc seeding systems. Avadex Xtra works best when incorporated by full disturbance to a depth of 50 mm.

Diuron

Diuron, a group C herbicide (substituted urea) had mix performances in the field and on sandier soil types had crop phototoxicity problems in wheat. One to 1.5 L/ha (\$7.86-\$11.79/ha) of the flowable 500 g/L formulation gave good control but again was soil type specific. Diuron performed well in mixtures.

MIXTURES

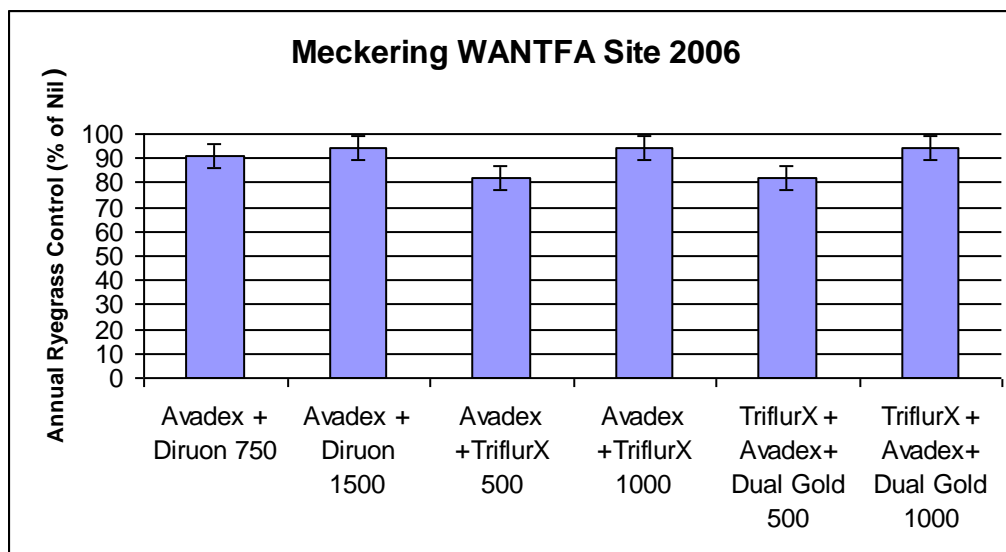


Figure 2. Performance of residual herbicides on annual ryegrass efficacy at Meckering in 2006. Figures after the herbicide name represent the dose in mL/ha of each product.

The results from Meckering in 2006 (Figure 2) represent a consistent response to controlling annual ryegrass from mixtures across multiple sites and years. In most cases there was a benefit of using higher doses indicating an additive effect of these herbicides. Preliminary glasshouse studies have indicated that there is no synergy associated with these mixtures.

Mixtures are seen as either a way to control hard to control weeds (such as herbicide resistant annual ryegrass) or to increase the spectrum of weeds it targets. Rarely are mixtures used to avoid herbicide resistance and will be discussed later. Trial work has demonstrated that Avadex Xtra (1 L/ha) mixed with Triflur X (500 mL/ha), Diuron (500 mL/ha) gave excellent control of annual ryegrass. A three way mix of Avadex Xtra (1 L/ha), Triflur X (500 mL/ha) and Dual Gold (500 mL/ha) also gave excellent ryegrass control. The exception to this was in a trial at Newdegate research station in 2006 in a population of trifluralin resistant annual ryegrass where mixtures that included trifluralin were inadequate. At higher doses crop yield damage was seen with the Diuron and Dual Gold mixtures at Meckering and Newdegate but not at Merredin, Wongan Hills or Mt Barker.

AVOIDING HERBICIDE RESISTANCE

There will be one and possibly two new products that will be released to the market in the near future (Boxer Gold and Argold) and possibly one in 5-10 years time (KIH485). The question is how we, the agricultural community, are going to look after these products given the history of herbicide resistance in Western Australia. Will we flog them until we get resistance (and it will happen) or will we try and avoid resistance so these products can still be available to us in 20-30 years time? Here are some strategies that will help to avoid or delay the onset of herbicide resistance.

Double knock

Double knock is a process where two different weed control strategies are imposed on the one population of weeds. If the second knock totally controls that population then you will NEVER get resistance (presuming the first knock is a herbicide) to the first herbicide. Paraquat after Glyphosate (double knockdown) is the most well known strategy but few do it correctly. The follow up application of paraquat MUST be at a high enough dose to kill the surviving plants outright. To make my point, 600-800 mL/ha of Spray.Seed 250 is not an adequate dose to kill annual ryegrass when tillering. Increase the rates of paraquat (or equivalent) to suit development stage and environmental conditions that allow total control in its own right. Other double knock strategies may include crop topping, seed catching and windrow burning. Remember that if no seed survives then you get a free shot of any herbicides you applied in that year.

Herbicide mixtures

Herbicide mixtures can be used to prevent or delay the development of herbicide resistance but rarely are they used correctly. To avoid resistance the dose of each herbicide must be at a rate that gives good control in its own right. While adding any kind of diversity may delay the onset of resistance, only use mixtures at full label rates if you are intending to avoid resistance. Low rates of herbicides used in mixtures will select for resistance to both of these herbicides at the same time.

Herbicide rotation

While rotating herbicides from year to year will not avoid the development of herbicide resistance it will delay it. You will still have the same number of 'shots' of that herbicide group but by using them every second year you will double the amount of time that this herbicide can be used. Always rotate with herbicides of different mode of actions. Rotating herbicides within herbicide groups will NOT delay the onset of resistance. There are some exceptions to this as the resistance pattern between some sub herbicide groups can be different but to be safe always chose herbicides from different groups.

Integrated Weed Management

Using as many weed management tools as possible will help avoid herbicide resistance and also combat resistant populations. Widening crop rotation is perhaps the most powerful IWM tool there is as it offers flexibility in weed control options. There are too many IWM options to discuss here but the key is to stop seed set or to prevent seeds from entering the seed bank. Always maintain an IWM approach even when weed numbers are low. This ensures that blow outs in weed populations do not take place and allows cropping to continue if that is your choice. And remember, if you achieve total weed seed control you give yourself a free shot at any of the herbicides you have used in that year.

KEY WORDS

herbicide resistance, trifluralin alternative, herbicide mixtures, new herbicide molecules, integrated weed management

ACKNOWLEDGMENTS

We are grateful to GRDC for funding the project (DAW00114). We are thankful to Ms Julie Roche and Mr Tom Sweeney for their technical help. Special thanks are due to all DAFWA Research Station Staff and WANFA for providing trial sites and all the research facilities.

Reviewed by: Peter Newman

Evaluation of a new pre-emergent herbicide alternative for the control of trifluralin resistant *Lolium rigidum* Gaudin (annual ryegrass) in wheat and barley

Craig A. Ruchs, Syngenta Crop Protection Australia Pty Ltd and Dr Peter Boutsalis, University of Adelaide

KEY MESSAGES

Recent surveys have shown *Lolium rigidum* Gaudin (annual ryegrass) resistance to the Group D (dinitroaniline) herbicides, including trifluralin, to be increasing in frequency across southern Australia. A resistance screen of 22 known trifluralin resistant annual ryegrass biotypes showed no cross resistance between trifluralin and a new pre-emergent herbicide, Boxer® Gold (coded A14429B) from Syngenta Crop Protection Pty Ltd. This finding has significant implications as it provides growers with a different herbicide mode-of-action for the control of annual ryegrass in wheat and barley.

INTRODUCTION AND AIMS

Trifluralin is now one of the most important herbicide options for the control of annual ryegrass and certain broadleaf weeds in minimum-till cropping systems. Increasing frequency of resistance to the Group A (ACCase inhibitors) and sulfonylurea (ALS inhibitors) herbicides has led to poor post-emergent annual ryegrass control and a greater emphasis on pre-emergent weed control. The advent of precision seeding systems has allowed higher use rates of trifluralin and enabled greater weed control by concentrating herbicide in the crop inter-row whilst still allowing adequate positional herbicide selectivity.

Resistance to trifluralin in *Lolium rigidum* Gaudin (annual ryegrass) was first reported in the mid 1980s (Heap and Knight 1986, Howat 1987). Recent surveys of herbicide resistance in annual ryegrass have highlighted increasing levels of resistance to the Group D mode of action (MOA) herbicides across southern Australia. A survey of the major cropping areas of South Australia showed 35-54% of annual ryegrass samples to have detectable levels of resistance to trifluralin and between 15-21% of samples had high level resistance to trifluralin (Boutsalis *et al.* 2006). This contrasts to Western Australian survey results indicating 0.2% resistance in a random survey of 500 seed samples (Llewellyn and Powles 2001). However, the increased frequency of resistance to ACCase and ALS inhibiting herbicides and increased reliance on herbicides under no-till systems will increase the pressure on Group D herbicides. It is therefore important that alternative pre-emergent herbicide options are evaluated in cereals in order to delay the onset of trifluralin resistance.

Boxer® Gold (tested as A14429B) is a new alternative MOA pre-emergent herbicide from Syngenta Crop Protection Pty Ltd currently being evaluated in Australian trials for use in cereals. The aim of this study was to determine the extent of cross-resistance between Group D herbicides and Boxer® Gold in annual ryegrass.

METHOD

In June 2006 a pot study was undertaken by the University of Adelaide to evaluate the efficacy of Boxer® Gold in the control of trifluralin resistant annual ryegrass. Annual ryegrass seed derived from biotypes confirmed as resistant to trifluralin in previous tests were selected for use in the study. Seed was placed on the surface of soil in pots and herbicides applied directly to both seed and soil. The herbicides were applied in a water volume of 106 L ha⁻¹ at a spray pressure of 250 kPa using a laboratory moving boom. Syntal F-01-110-S nozzles were fitted to the boom and spray speed was 3.6 kph. Following herbicide application, seed was covered with untreated soil to a depth of 5 mm.

The experiment was conducted outdoors during the normal growing season in June 2006. A known trifluralin-susceptible (S) and two known trifluralin-resistant populations (R1 and R2) were included in the test. Use rates of trifluralin evaluated were 0, 200 and 400 g a.i. ha⁻¹, with Boxer® Gold tested at use rates of 0, 1250 and 2500 g ha⁻¹ of product. Use rates evaluated are comparable to field use rates when the relative higher activity of herbicides in pot trials is taken into account.

All pots were watered immediately after covering with soil and emergence of seedlings measured 28 days after spraying. Seedlings were considered emerged if they had reached the 2-leaf stage at this time.

RESULTS

Trifluralin provided complete control of the known susceptible population (S) at the two use rates evaluated. The low rate of 200 g a.i. ha⁻¹ did not give adequate control of either resistant population standard (R1 and R2) and resulted in survival of other populations ranging from 33% to 100% (refer Figure 1). This rate is likely to reflect field efficacy of trifluralin 480 applied at 2.0 L ha⁻¹, with five populations in this study exhibiting 100% survival to this rate of herbicide. The 400 g a.i. ha⁻¹ rate of trifluralin provided 66% control of the moderately resistant population R1 but only 23% control of R2, with five populations exhibiting less than 40% control using 400g a.i. ha⁻¹ trifluralin.

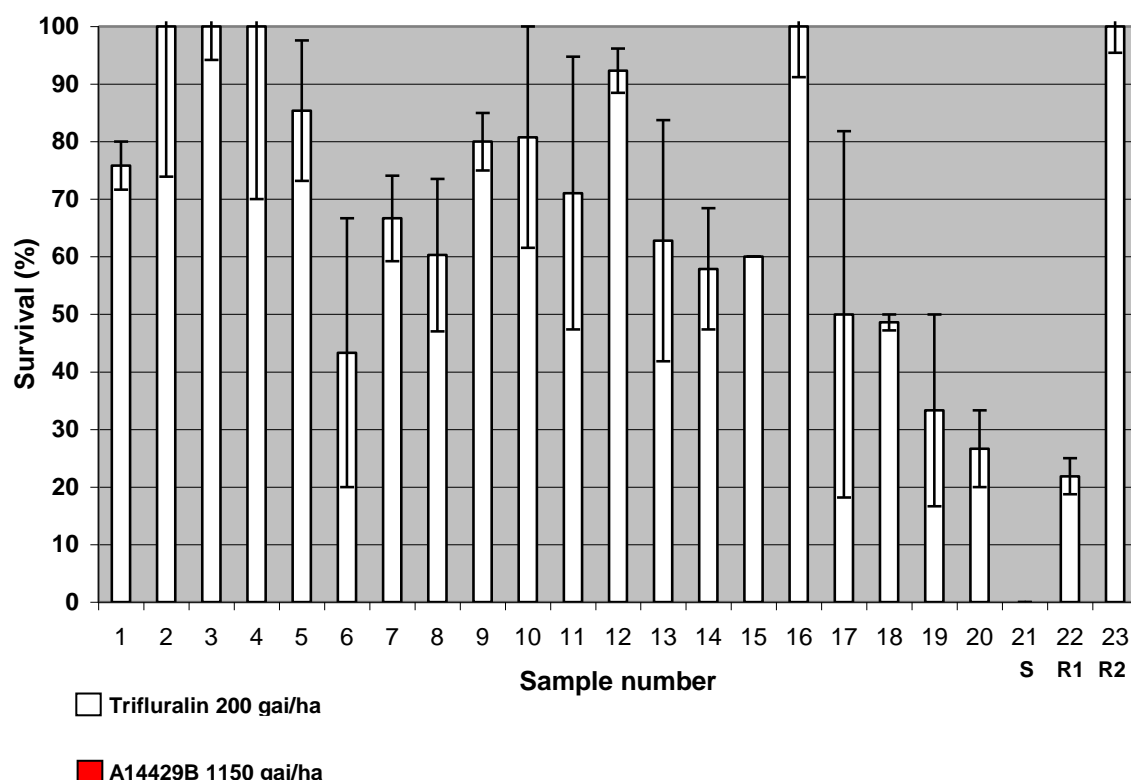


Figure 1. Efficacy of trifluralin and Boxer® Gold (A14429B) on 22 trifluralin resistant ryegrass biotypes. R1 and R2 are two standard resistant biotypes and S represents a known herbicide-sensitive biotype. Results are presented as percent survival at 28 days after treatment relative to untreated control pots. Standard Error bars show deviation of the mean.

Boxer® Gold provided complete control of the known trifluralin susceptible population (S) at both use rates evaluated. The study found Boxer® Gold to be fully effective on all 22 known trifluralin resistant annual ryegrass biotypes. No survival was recorded for any biotype treated with even the lowest rate of Boxer® Gold. These results show promising results for the future use of Boxer® Gold in situations where trifluralin is not effective and/or provides growers with a rotational option to maximise the effective use life of trifluralin.

CONCLUSION

The results of this study demonstrated that a new pre-emergent herbicide, Boxer® Gold, was effective in controlling 22 known trifluralin resistant annual ryegrass populations. It can therefore be concluded that none of the populations evaluated in this study exhibited cross resistance between trifluralin and Boxer® Gold.

KEY WORDS

trifluralin, annual ryegrass, resistance, efficacy

ACKNOWLEDGEMENTS

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Boxer® is a registered trademark of Syngenta Crop Protection Pty Ltd.

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Project No.: UA00075

Paper reviewed by: Dr Christopher Preston, University of Adelaide

Novel knockdown tank mixes: Results from 12 trials over four years

Shahab Pathan¹, Abul Hashem², Catherine Borger³, Nerys Wilkins¹ and Julie Roche², Department of Agriculture and Food, Western Australia, ¹Merredin, ²Northam and ³the University of Western Australia

KEY MESSAGES

- Mixtures of Roundup® Power Max or Spray.Seed® with other herbicides significantly improved weed control compared to using a single herbicide.
- Spray.Seed® + Lexone® at full rates controlled 92 to 100%, and Roundup® Power Max + Hammer® at full rates controlled 96 to 100% broadleaf and grass weeds.
- Use of tank mixes consisting of herbicides from two or more mode of action groups may delay the development of herbicide resistance longer than using one herbicide alone.
- Emergence and growth of wheat and barley were not affected by residual chemical toxicity.

BACKGROUND

Herbicide mixtures are used to increase the spectrum of weeds controlled and advocated to minimise or delay the development of herbicide resistance. Mixtures are widely used in WA agricultural systems. Herbicide mixtures consisting of herbicides from two or more mode of action groups have the potential to be used in IWM systems to prevent the development of herbicide resistance (Diggle *et al.* 2004). Some herbicides perform more effectively in the presence of additional herbicides than they do when applied alone.

Results obtained in the trials 02NO34, 03NO36 indicated that half rates of some herbicides in mixtures were as effective as full rates (Hashem and Borger 2003). However, it is recommended that label rate of each herbicide should be used in a mixture for herbicide resistance management (Gressel and Segel 1990, Wrubel and Gressel 1994).

AIMS

- To determine the most effective knockdown-based novel herbicide mixture(s) that reliably provides high weed mortality to a broad spectrum of weeds.
- To minimise the development of herbicide resistance.
- To identify mixtures that are safe to emerging crops (no adverse residual activity).

METHODS

Over the period 2003 to 2006 a total of twelve trials were conducted during the growing season at Avondale, Esperance, Meckering, Merredin and Wongan Hills in Western Australia.

Table 1. The following herbicides were used with Roundup® Power Max (glyphosate 540 g/L) or Spray.Seed® (paraquat 135 g/L + diquat 115 g/L) in one, two, three or four way tank mixtures

Herbicides	Products used*	Active ingredient concentration
Metribuzin	Lexone®	750 g/kg
Diuron	Diruex®	900 g/kg
Carfentrazone-ethyl (EC)	Hammer®	240 g/L
Oxyfluorfen	Striker®	240 g/L
Trifluralin	Triflur X®	480 g/L

* Note the use of a particular product does not imply a preference/recommendation for those particular products. Alternative products with the same active ingredient (and a.i. concentration) may perform similarly to those products specified.

For each mixture the herbicides were applied at the full label rates and also at $\frac{1}{2}$ label rates for two way mixtures, $\frac{1}{3}$ rates for three way mixtures and $\frac{1}{4}$ rates for four way mixtures. All the non-selective herbicide mixtures were sprayed directly before seeding, five days prior to seeding and 15 days prior to seeding. In 2006, Triflur X[®] (trifluralin 480 g/L) was incorporated by seeding and Achieve[®] (tralkoxydim 400 g/kg) was sprayed at the 3 to 4-leaf stage of wheat and barley as additional treatments.

Crops (wheat cultivars such as Arrino, Spear, Wyalkatchem, and barley cultivars such as Baudin, Hamelin, Stirling) were sown at 75 kg/ha (wheat) and 80 kg/ha (barley), using no-till system and standard agronomic practices of the region. The dominant weed species at the trial sites were annual ryegrass, barley grass, cape weed and wild radish. The measurements included density of crops and weeds by species, weed mortality, crop/weed dry biomass, ryegrass heads and grain yields.

RESULTS

Two way mixes of Roundup[®] Power Max or Spray.Seed[®] with other herbicides at full label rates significantly improved weed control efficacy over a knockdown alone in most locations (Table 2 and Table 3). For example, control of grasses and broadleaf weeds was 96 to 100% by Roundup[®] Power Max + Hammer[®] at Merredin and Avondale (Table 2). This tank mix controlled 96% grasses and 85% broadleaf weeds at Wongan Hills compared to 83% and 64% respectively by Roundup[®] Power Max alone. Spray.Seed[®] + Lexone[®] at full rates controlled 100% broadleaf weeds and 92 to 99% grasses while Spray.Seed[®] alone controlled 82 to 95% grasses and 61 to 88% broadleaf weeds across locations (Table 2). Some mixtures provided adequate weed control even at lower rates of mix components (Table 2).

Table 2. Weed control (%) assessed after spraying knockdowns or knockdown-based tank mixes at Avondale, Merredin and Wongan Hills in 2005

Treatments and product rate (g or mL or L/ha)*	Merredin		Wongan Hills		Avondale	
	Grasses	Broad-leaf	Grasses	Broad-leaf	Grasses	Broad-leaf
1. Untreated control	0.0	0.0	0.0	0.0	0.0	0.0
2. Roundup [®] PM 1.0 L	90	89	83	64	83	94
3. Roundup [®] Power Max 1.0 L + Lexone [®] 280 g	89	99	83	78	83	100
4. Roundup [®] Power Max 0.5 L + Lexone [®] 140 g + Diruex [®] 1.0 L	77	97	67	75	67	89
5. Roundup [®] Power Max 1.0 L + Hammer [®] 80 mL	100	98	96	85	96	99
6. Roundup [®] Power Max 0.5 L + Hammer [®] 40 mL + Diruex [®] 1.0 L	91	86	67	57	67	72
7. Spray.Seed [®] 1.5 L	95	88	82	61	82	80
8. Spray.Seed [®] 1.5 L + Lexone [®] 280 g	99	100	92	100	92	100
9. Spray.Seed [®] 0.75 L + Lexone [®] 140 g + Diruex [®] 1.0 L	91	96	89	78	89	95
10. Spray.Seed [®] 1.5 L + Hammer [®] 80 mL	98	92	93	80	93	79
11. Spray.Seed [®] 0.75 L + Hammer [®] 40 mL + Diruex [®] 1.0 L	75	82	72	72	72	73
lsd (p = 0.05)	8.3	12.9	13.9	14.6	13.9	11.0

* In treatment list '+' indicates tank mixes.

Emergence and growth of wheat and barley were not affected by residual chemical toxicity whether sown directly after spraying, five days after spraying or 15 days after spraying. The one exception however was where, both wheat and barley crops grown on a TT canola stubble at Meckering WANTFA site, were damaged up to 40% when treated with Lexone[®] in 2006. This was presumably due to cumulative effect of residual triazine herbicide from 2005 and the Lexone[®] within the mixture of herbicides.

In-crop residual weed control was evident where mixtures of knockdown herbicides with Lexone® and Diruex® were used in some sites. In 2006, residual weed control has been compared with Triflur X® at five different locations (Table 3).

Table 3. Ryegrass heads (number/m²) at five locations grown in wheat and barley treated with different herbicides (alone or in mixtures) measured at mature stage in 2006

Treatments and product rate (g or mL or L/ha)*	Merredin		Avondale		Wongan Hills		Esperance		WANTFA	
	W*	B*	W	B	W	B	W	B	W	B
1. Untreated control	56	41	195	69	319	218	267	134	95	127
2. Roundup® Power Max 1.0 L	50	8	87	3	29	34	24	12	38	4
3. Roundup® Power Max 1.0 L/Triflur X® 1.5 L IBS*	37	8	5	2	26	26	5	3	2	1
4. Roundup® Power Max 1.0 L/Triflur X® 1.5 L IBS/Achieve® 380 g PO*	8	1	18	0	10	14	0	0	8	0
5. Roundup® Power Max 1.0 L + Hammer® 80 mL	30	15	45	6	40	45	32	21	25	3
6. Roundup® Power Max 1.0 L + Hammer® 80 mL/Triflur X® 1.5 L IBS	12	2	10	1	19	27	7	2	7	0
7. Roundup® Power Max 1.0 L + Hammer® 80 mL/Triflur X® 1.5 L IBS/Achieve® 380 g PO	5	1	18	1	21	16	1	0	4	1
8. Spray.Seed® 1.5 L	50	7	27	10	52	61	43	23	31	7
9. Spray.Seed® 1.5 L/Triflur X® 1.5 L IBS	18	2	27	1	22	40	4	5	5	4
10. Spray.Seed® 1.5 L/Triflur X® 1.5 L IBS/Achieve® 380 g PO	25	5	0	1	19	39	0	4	0	0
11. Spray.Seed® 1.5 L + Lexone® 280 g	32	6	19	3	21	52	3	3	27	1
12. Spray.Seed® 1.5 L + Lexone® 280 g/Triflur X® 1.5 L IBS	0	1	6	4	33	51	0	0	17	1
13. Spray.Seed® 1.5 L + Lexone® 280 g/Triflur X® 1.5 L IBS/Achieve® 380 g PO	1	1	15	4	51	33	5	0	7	0
Isd (p = 0.05)	28	11	90	10	22	44	21	20	25	11

* In treatment list '+' indicates tank mixes; W = Wheat; B = Barley; PO = Post emergence; IBS = Incorporated by seeding.

Crop emergence tended to decline with delay in sowing time and crop growth was inversely related to the level of weed control. Grain yield of wheat and barley were inversely related to the level of weed control (Figure 1).

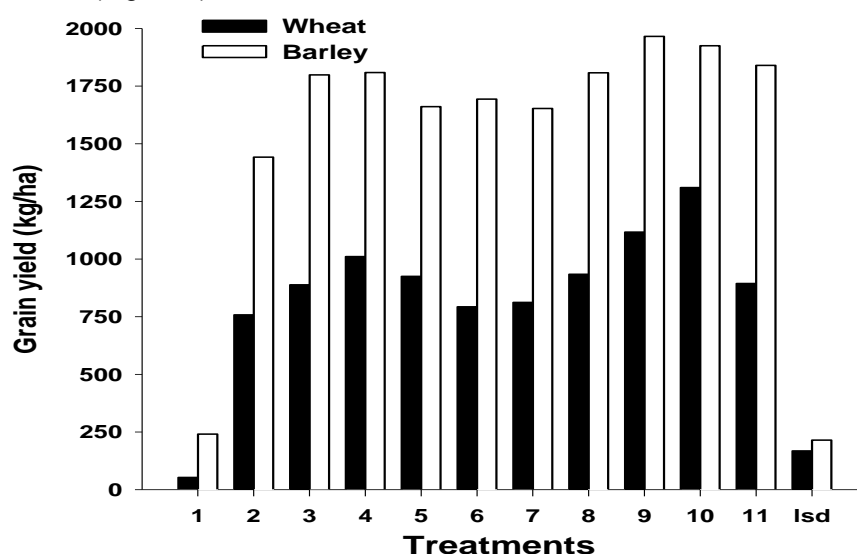


Figure 1. Grain yield of wheat and barley averaged over three time of sowing under different herbicide mixture treatments (see Table 1) at Wongan Hills in 2005.

CONCLUSIONS

It seemed likely that herbicide mixtures at full rate provide a broader spectrum of weed control than a single knockdown herbicide treatment of Roundup® Power Max or Spray.Seed®.

Roundup® Power Max + Hammer® at full rates controlled 96 to 100% broadleaf and grass weeds.
Spray.Seed® + Lexone® at full rates controlled 100% broadleaf weeds and 92 to 99% grass weeds.

Emergence and growth of wheat and barley were not affected by the trialled herbicide mixtures in 11 out of 12 trials even when sown directly after spraying.

Using several herbicides from different groups reduces the risk of herbicide resistance development to a greater extent than rotating herbicides between years. A weed resistant to one group of herbicide will be killed by the second group of herbicide and so fewer resistant plants survive to maturity, and add resistant seed to the soil seed bank.

Further work is required to identify more mixture options and their residual effects on following crop growth and yield. Work is also required to determine if the mixtures that are effective at reduced rates are actually synergistic.

KEY WORDS

knockdown tank mixes, herbicide resistance, weed control, wheat, barley, grain yield

ACKNOWLEDGEMENTS

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Project No.: DAW00114

Paper reviewed by: Vanessa Stewart

Alternative herbicides for weed control in lupins

Peter Newman and Martin Harries, Department of Agriculture and Food, Western Australia

KEY MESSAGES

Metribuzin applied at a high rate pre-sowing of lupins achieved excellent weed control and crop safety. The safety of metribuzin pre-sowing in a wet season may be a problem. Isoxaben early post emergent with simazine pre gave good results. All other experimental herbicides were either damaging to lupins, gave poor radish control or both.

AIMS

To discover new herbicide options for broadleaf weed control in lupins.

METHOD

The trial was a strip plot design of 16 herbicide treatments plus and minus Simazine (500) 2 L/ha pre-sowing. All herbicide treatments were applied by ground spray rig (water rate 70 L/ha). Mandelup lupins were sown dry on 30 May 2006 by cone seeder fitted with knife points and press wheels. Lupins were assessed visually for phytotoxicity symptoms using a biomass rating scale of 0 to 100 with 0 being dead lupins and 100 being 100% lupin biomass. Wild radish and doublegee were assessed by counting surviving weeds per plot. Plots were 3 m x 12 m. The trial site was good deep yellow sand located 25 km north of Mingenew. The paddock was in pasture in 2005.

RESULTS

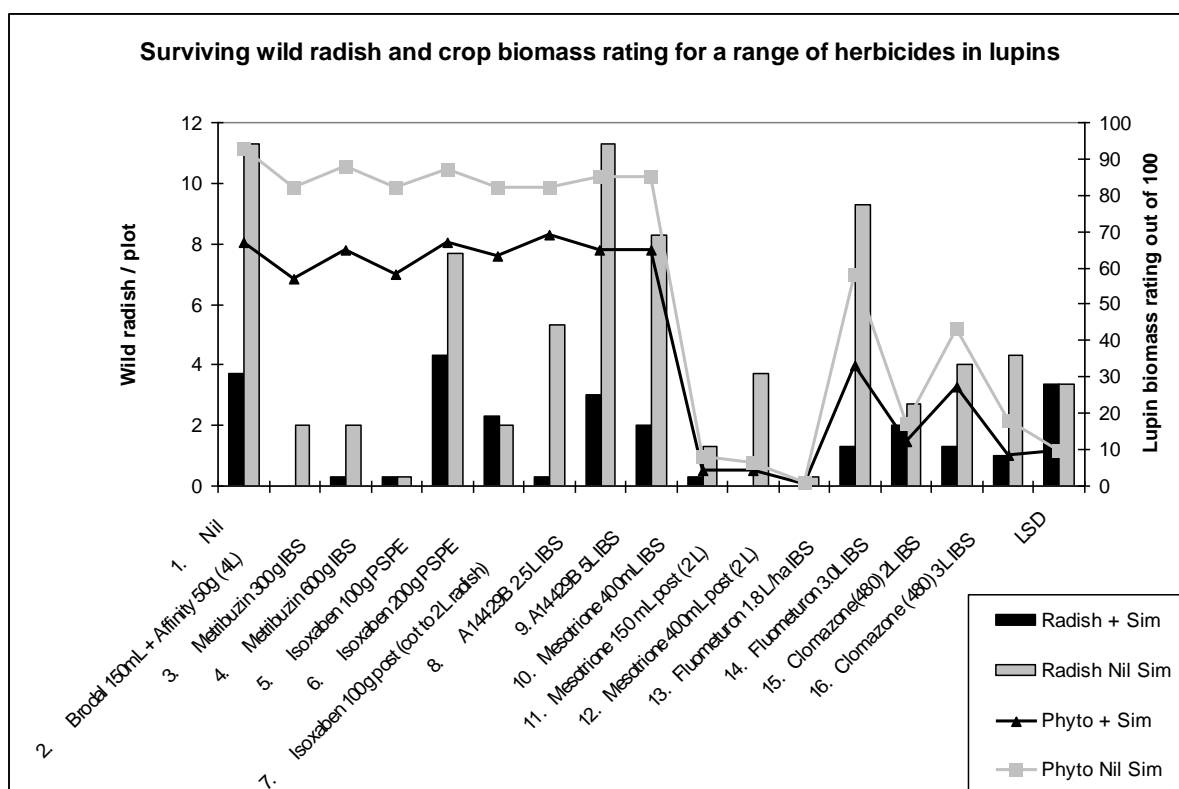


Figure 1. Surviving wild radish per plot and lupin biomass rating out of 100 for a range of herbicide treatments plus and minus simazine.

Table 1. Surviving wild radish and doublegee and lupin biomass rating plus and minus simazine

	Wild radish per plot	Doublegee per plot	Lupin Biomass rating (score out of 100)
Nil Simazine	4.75	7.3	57.4
Plus Simazine	1.4	1.1	41.5
Isd	1.2	4.5	3.4

CONCLUSION

Simazine pre sowing caused significant damage to the lupins at this site. Rainfall was well below average with approximately 80 mm rain falling during the growing season. It is likely that simazine damage occurred as a result of the lupins accessing most moisture from the top 20 cm of soil where the simazine was in a concentrated band. This high level of simazine activity on the lupins also led to high levels of weed control with simazine. Simazine 2 L/ha gave 67% wild radish control and 60% doublegee control.

Metribuzin 300 g/ha pre sowing gave 82% wild radish control and when combined with Simazine gave 97% wild radish control. Metribuzin pre sowing caused minimal damage to the lupins. Metribuzin is over 300 times more soluble in water than Simazine. Metribuzin has a relative strength of adsorption on soil (Koc) of less than half that of Simazine. Given these properties, it is likely that in wet conditions, these high rates of metribuzin will damage lupins. Research will continue in this area.

Isoxaben (Gallery®) at 200 g/ha post-sowing, pre-emergent resulted in 82% wild radish control with or without simazine. Isoxaben applied at the 2 leaf stage of the lupins where simazine was applied pre sowing resulted in 97% wild radish control with minimal crop damage from the isoxaben. Previous research has demonstrated that lupins are very tolerant of Isoxaben. However, the high rates necessary to control wild radish are cost prohibitive at current prices. Isoxaben is currently not registered for use in lupins and is therefore not recommended. Ongoing research will involve working with industry to explore the future registration of this product.

Brodal + Affinity is an experimental brew that has shown variable results. In this trial there was limited damage to the lupins however previous research has shown significant damage. Affinity® (Carfentrazone ethyl) is not registered for use in lupins and probably never will be. However, Yellow lupins show high levels of tolerance so research will continue.

A14429B is an experimental herbicide that may be registered in the near future. This herbicide is primarily for ryegrass control, however it has demonstrated some suppression of wild radish. There was some evidence of this at the high rate of 5 L/ha.

Mesotrione (Callisto®, unknown herbicide group) is a new herbicide that was discovered by a scientist who noticed that no weeds grew under a bottlebrush in his garden. Mesotrione was isolated from the soil and is registered as Callisto® for use in corn in the USA. Mesotrione was very damaging to all weeds and the lupins. If only we could find a crop that is tolerant to this herbicide! Flumeturon (Cotoran®, Convoy®, Group C Urea) is registered for use in Cotton. In this trial Flumeturon damaged lupins and did a poor job on wild radish. Clomazone (Group F) is registered for use in Soybean and Cotton. In this trial Clomazone turned the lupins a bright white colour and only suppressed the wild radish.

KEY WORDS

lupin, metribuzin, isoxaben, simazine

ACKNOWLEDGMENTS

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Project No.: DAW00123

Paper reviewed by: Martin Harries

Novel use application of clopyralid in lupins

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KEY MESSAGES

- Clopyralid has activity on cape weed, skeleton weed and some thistles.
- Clopyralid is registered for use in cereal crops but not registered for use in lupins.
- Albus lupins will not tolerate clopyralid but several narrow leaf varieties will tolerate up to 450 mL/ha pre-sowing and 100 mL/ha post-emergent.
- Further research is required to indicate potential to use clopyralid pre-sowing and also post-emergent to control/suppress blue lupins, albus varieties of lupins, cape weed, thistles and skeleton weed in narrow leaf lupins.

AIMS

To evaluate the herbicide tolerance of narrow leaf lupins to clopyralid.

METHOD

A split plot design having three replications in both the main and sub plots was used for the trial at the Eradu Sandplain Research Anex in 2005. The site was burnt on 5 April. Pre-sowing treatments clopyralid (300 g a.i.) of 0, 150, 300 and 450 mL/ha were applied to the main plots on 20 April 2005. Spray.Seed® 1 L/ha and simazine 2 L/ha were applied over the entire trial on 6 May. Narrow leaf lupin Mandelup were sown at 100 kg/ha with 100 kg superphosphate on 16 May 2005 using bulk seeding equipment fitted with press wheels. Crop maintenance included dimethoate 800 mL on 25 May and applications of 150 mL/ha Brodal® plus 0.5 L simazine on 14 June. Further grass weed control was carried out on 27 June using Fusilade® 70 mL, Select® 250 mL and Hasten® 500 mL/ha. Post emergent applications of clopyralid at 0, 50, 75 and 100 mL/ha were applied to the sub plots at two different times 22 June and 19 July 2005. Additional insect control was carried out with the trial treated with Dimethoate 800 mL and Fastac Duo® 300 mL/ha to control aphids and other pests in early and late September. Plots were machine harvested in November.

RESULTS

The narrow leaf lupin Mandelup tolerated up to 450 mL/ha of clopyralid pre-sowing and post-emergent applications up to 100 mL without showing any significant yield losses (Table 1). No measurements were taken but observations noted that clopyralid also was more damaging on the blue (sandplain) lupins contaminating the trial site.

CONCLUSION

Work carried out by Dhammu and Nicholson and reported in crop updates 2006 (Weed Updates pp. 79-83 and 87-89) confirmed the tolerance of narrow leaf lupins to clopyralid and also the susceptibility of the albus lupins. The gap in tolerance would indicate the possibility of controlling or suppressing the albus and the cosentinii varieties (blue lupins) growing in narrow leaf (angustifolius) lupin crops as well as many other weeds such as capeweed and some thistles susceptible to clopyralid.

In addition the use of clopyralid in lupins has another benefit in the eradication of skeleton weed. This weed causes significant yield losses in cereals and its density increases dramatically, probably because of nitrogen fixation, when the weed infests lupins. The weed is currently under an eradication program in Western Australia and clopyralid is used extensively where large infestations of skeleton weed are found in cereals. If it can be used in the lupin as well as the cereal phase it will contribute greatly toward the possibility of eradication as currently there are no herbicides registered for use against skeleton weed in Western Australia.

Table 1. Effect of clopyralid on yield (t/ha) of narrow leaf lupins treated pre-sowing and post emergence

Post-emergent		Pre-sowing Clopyralid mL/ha				Post em averages
Clopyralid mL/ha	Application time	150	300	450	Nil	
50	22 June 2005	2.44	2.41	2.43	2.52	2.45
75		2.37	2.26	2.33	2.22	2.30
100		2.39	2.17	2.22	2.24	2.25
Nil		2.43	2.33	2.35	2.20	2.33
50	19 July 2005	2.31	2.35	2.35	2.22	2.31`
75		2.33	2.26	2.22	2.28	2.27
100		2.35	2.24	2.30	2.24	2.28
Nil		2.30	2.28	2.33	2.26	2.29
Pre-sowing averages		2.37	2.29	2.32	2.27	

Isd (0.05)

Pre treatments – 0.09

Post treatments – 0.16

KEY WORDS

narrow leaf lupins, blue (sandplain) lupins, skeleton weed, clopyralid tolerance

ACKNOWLEDGMENTS

Grateful acknowledgement of funding from the Skeleton weed Eradication Trust Fund.

Paper reviewed by: Dr Aik Cheam

A model to predict grass selective herbicide rates

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KEY MESSAGES

The rate of group A grass selective herbicides required for a particular level of weed control can be predicted on a daily basis.

These rates may vary several fold over time, location or season.

The effects of adverse conditions may be reduced by increasing water rates.

The model automatically retrieves weather and other data from the internet and will predict rates based on historic data and/or forecasts up to five days into the future. This is incorporated into the HerbiGuide program to provide label rates and other information for better decision making.

AIMS

Poor performance of herbicides is often attributed to poor conditions and many herbicide labels have statements like “apply to actively growing plants” and “do not apply to weeds under stress”. It has been difficult for operators and advisers to determine when these conditions occur and if adjusting the herbicide rate is appropriate. On most labels there is a single rate on the label for a particular weed and crop situation. This is the rate that provides adequate control over the normal range of conditions experienced. Herbicide dose response trials¹ show that the rate of herbicide required for a given weed control level can vary several fold within and between seasons. Andrews *et al.* (2006)² have also analysed the effects of weather and spray volume on the efficacy of clodinafop (Topik® a group A herbicide) on wild oats (*Avena* spp.).

This paper presents a user friendly model to help advisers and operators determine the rate of group A herbicide that is likely to be required to give a particular level of control with a particular confidence. The data of Andrews *et al.* (2006)³, Minkey and Moore (1998)¹, companies and agricultural departments were used to produce and verify the model.

The aim of this work was to provide growers and advisers with the best information on group A efficacy with minimum effort. Eight easy input parameters are required; emergence date, spray date, location, soil type, nutrient status, water volume, kill level and confidence. From these, all other data such as temperature, rainfall, evapotranspiration, soil moisture, growth rate and dose responses are calculated or retrieved automatically from the internet.

METHOD

Regression analysis based on the model of Andrews *et al.* (2006) was applied to the data for clodinafop and diclofop¹. Predictions from these equations for other group A herbicides were compared to trial and farmer results from HerbiGuide⁴. Weather data is retrieved from the internet based on the closest weather station to the site of herbicide application. From this data the soil moisture is calculated. This dose response curve is then adjusted for soil nutrient status based on Moore and Minkey (in press). To run the model the user enters the emergence and spray date for the weeds, the water volume, nutrient status, soil type, the closest Bureau of Meteorology weather station, the level of weed kill and the confidence level required. Several runs of the model are presented showing the effects of changing the various input parameters, the season and the location.

RESULTS

The graph in Figure 1 shows the rates of clodinafop required to give an average 95% control of wild oat at Merredin in 2006 on a sand soil with good nutrient status and a water volume for spraying of 50 L/ha as it is displayed in HerbiGuide.

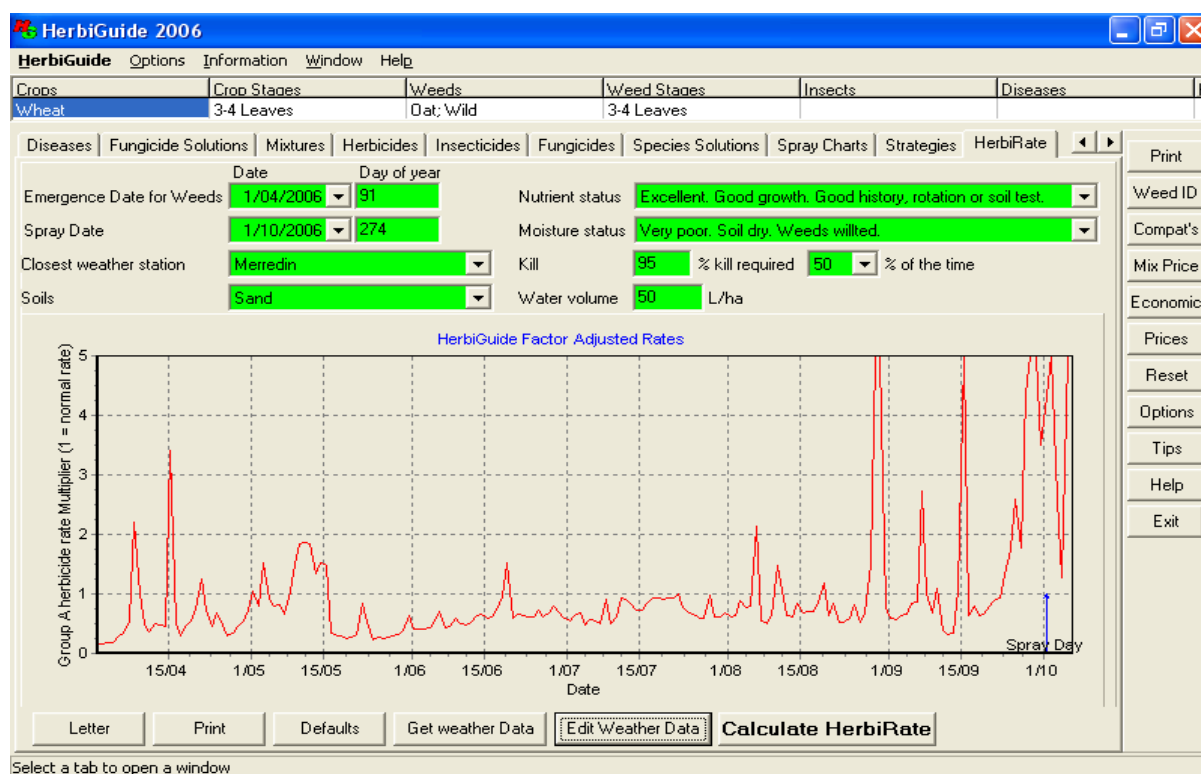


Figure 1. The input parameters required to predict the rate multiplier for clodinafop on a daily basis.

During most of the normal spraying period in June and July lower than label rates can be used, however there are a few days when considerably higher rates are required. For example, in Figure 2 for a proposed spray date of June 16, the rate multiplier is 0.58 (i.e. 58% of the label rate is expected to provide a 95% kill on average). Using forecast weather conditions the rate required is expected to rise to about 1.44 times the label rate by 19 June and fall on 20 June.

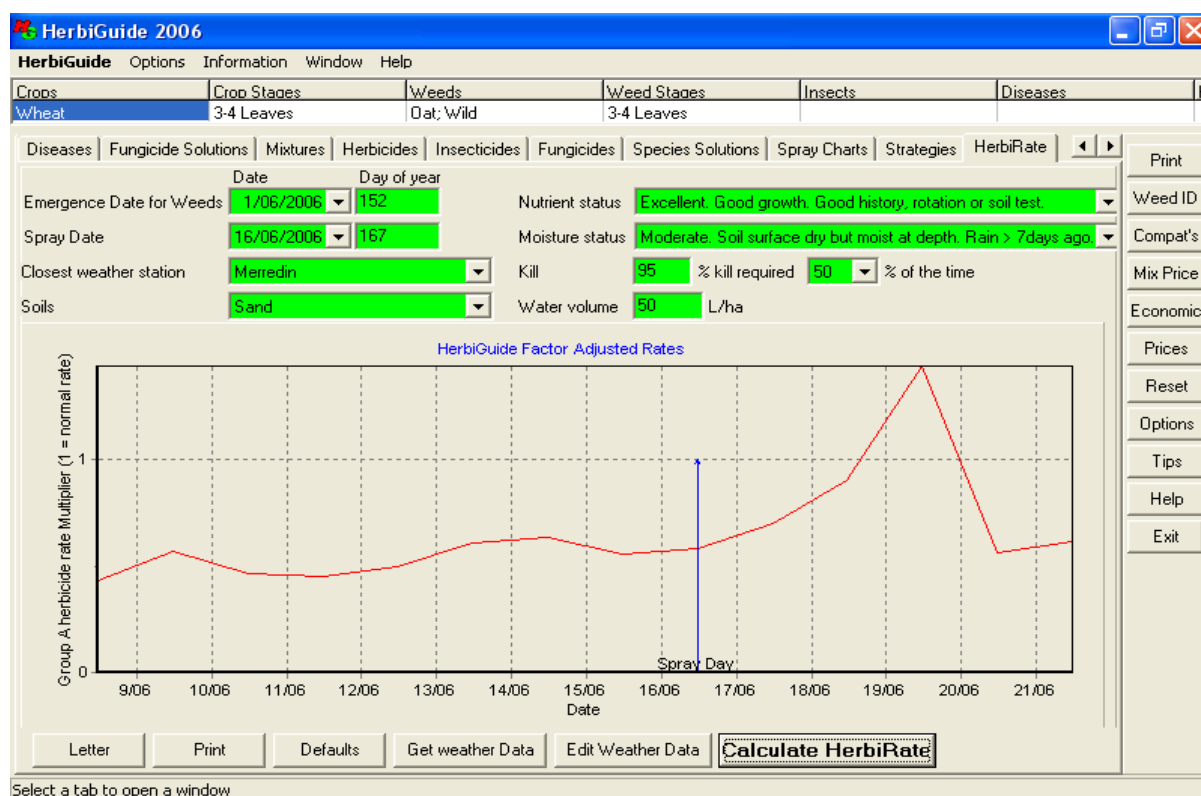


Figure 2. The rates of clodinafop required on a particular day using the five day forecast to determine the rates required for future spraying.

Over the same period higher rates were required at Carnamah and Katanning and lower rates at Esperance (Figure 3). The rates required at Esperance never exceeded the label rate in contrast to Katanning where rate required was greater than label rates for most of the period. In fact on 19 June the herbicide rate required at Esperance is less than half that required at other locations for the same job. This is reflected in the agronomists views that grass control in the great southern was marginal this year compared to Esperance where generally very good control was achieved. The model should help advisers calibrate themselves more quickly to reflect seasonal and daily conditions especially where they are providing advice over widely separated locations such as the AgLine service of the Department of Agriculture and Food.

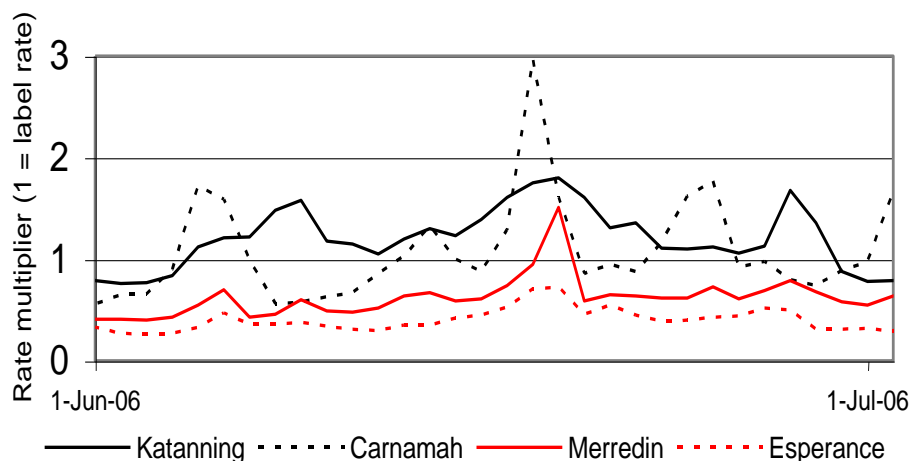


Figure 3. The rates required at various locations in 2006.

Figure 4 shows the predicted rates at Wongan Hills over the last three years. In 2004, good control was always achieved with less than half the label rates. In 2005, rates generally had to be higher but never exceeded label rates whilst in 2006 there were periods when higher than label rates were required to give 95% control.

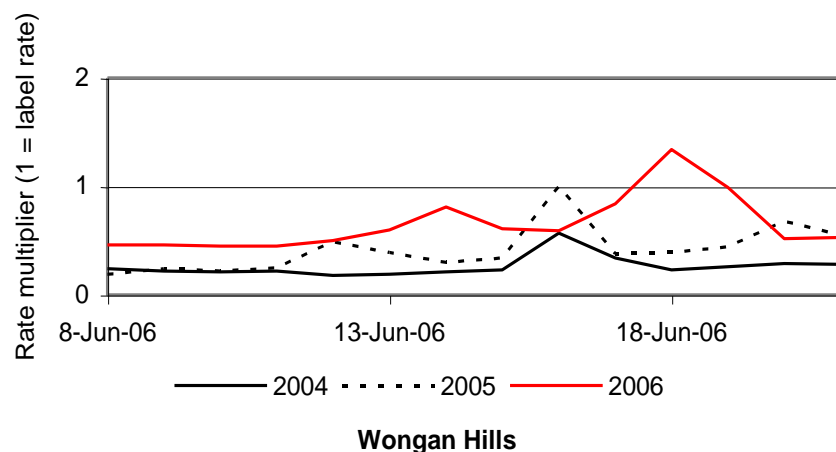


Figure 4. The effect of season on the rate of clodinafop required.

Changing the control level or confidence levels has a major impact on the predicted rates. Taking Esperance as an example in Figure 5 over the normal spraying period it can be seen that 95% control of wild oats on average can be achieved with about half the label rate of herbicide. However, if the grower wants to be sure of achieving a 95% control level 95% of the time (or 19 times out of 20) then double rates are usually required. The label rate corresponds to about 90% kill in 90% of situations.

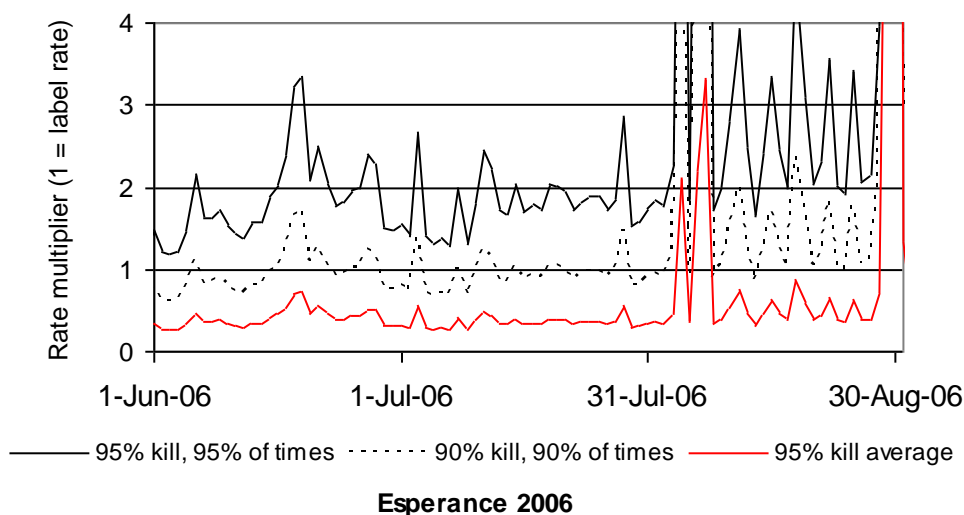


Figure 5. The effect of changing the control and confidence levels on the herbicide rates required.

Using the Carnamah example, because stressed conditions occurred there in 2006, changing the water rate can reduce the amount of herbicide required for a particular level of efficacy particularly under stressed conditions. The 100 L/ha line in Figure 6 is not only lower but also less variable than the higher 50 L/ha line. If high rates are predicted for a particular spraying date the grower has the option of using higher water volumes in these periods and/or saving water during periods more suitable for spraying.

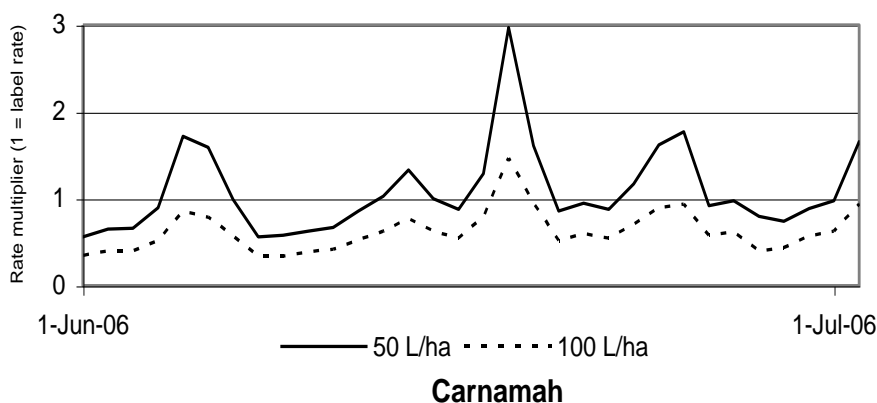


Figure 6. The effect of water rate on predicted clodinafop rate.

The results of this model are summarized in the normal HerbiGuide output in Figure 7. The user now has the label rate, the common use or trial rate and a factor adjusted rate for the day of spraying and location to help them make a decision on the most profitable rate of Topik® to apply. In this case the savings in herbicide are about \$7/ha. In other cases where the adjusted rate is considerably higher than the label rate then the increased profit comes from increased yields by using a higher rate or delaying weed control until conditions improve. Monza® has no adjusted rate because it is a group B herbicide and the work has not been done to determine the factors affecting it.

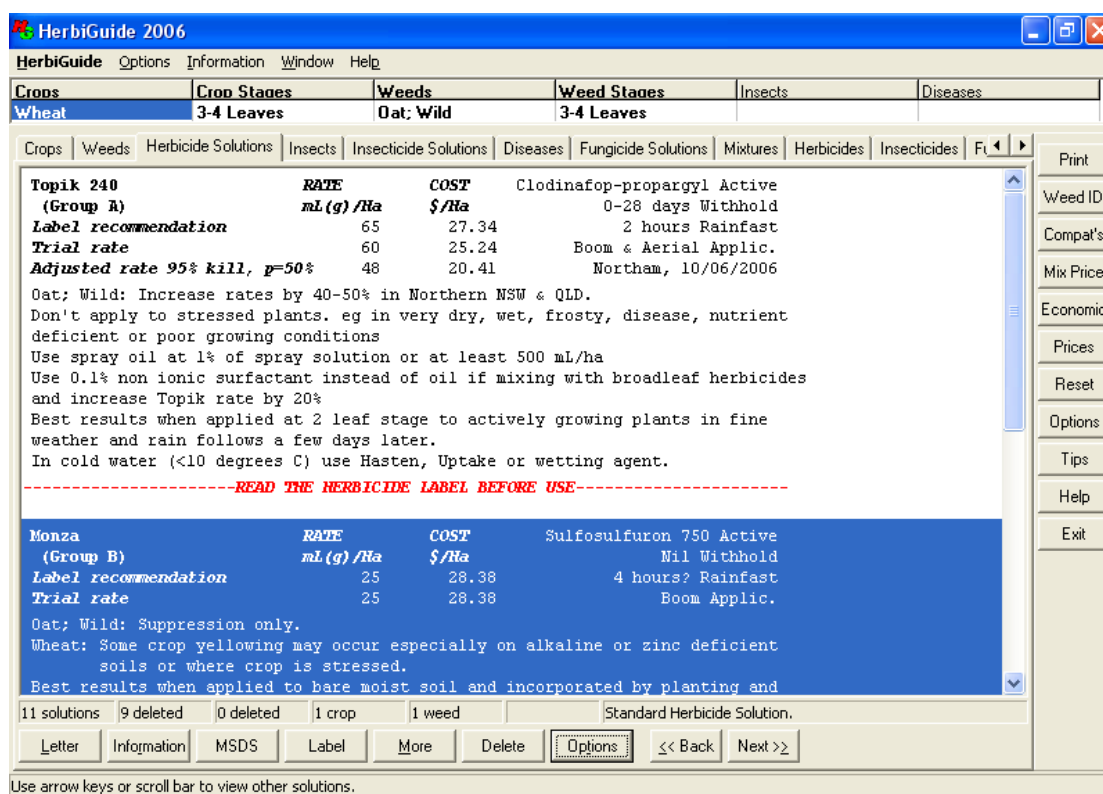


Figure 7. The summary results in HerbiGuide.

Limitations

The clodinafop model on wild oats accounts for about 30% of the variation in the trial data. This may be improved by the addition of the nutrient status in the current model. Whilst the model is used to predict the rates of other group A herbicides its accuracy is expected to be less. Many factors affecting herbicide performance are not included in this model such as resistance, competition from crop and other weeds, time of relative emergence, farming system, frost, waterlogging, insect, disease and other stresses. There are no significant economic considerations in the current model.

CONCLUSION

There are large differences in the rate of group A herbicides required to give satisfactory weed control over short time spans of a few days to weeks. There are also large differences between sites on the same day of spraying and also between seasons. These effects are difficult to predict by field observation so use of the model should lead to both better advice and more reliable weed control.

It is also useful in the analysis of herbicide failures to determine whether it was just conditions on the day or other factors such as herbicide resistance that caused the failure.

The ability to forecast rates five days into the future allows growers to adjust their spraying times or analyse the benefits of more efficient equipment as well as adjust rates.

In some states there will be regulatory issues that need addressing.

The model provides an easy way of checking the influence of major environmental factors on group A herbicide performance to allow better decisions about the rates to be applied. The integration with the HerbiGuide program provides a convenient platform for accessing other weed control information such as costs, restraints, labels, MSDS sheets, rates, biology, economic and other information.

KEY WORDS

herbicide, dose, rate, wild oat, Avena, Lolium, rigid ryegrass, cereal, group A, grass-selective, wheat, model, HerbiRate, HerbiGuide, clodinafop, diclofop, Topik, Hoegrass

ACKNOWLEDGMENTS

The GRDC provided funding for Minkey and Moore (1998) and to the CRC for Weed Management for the data and analysis of Andrews *et al.* (2006). Bayer provided much of the original data from diclofop and clodinafop trials. The Bureau of Meteorology supplies the weather data. Many other companies, Departments of Agriculture, GRDC projects, farmers and advisers have provided trial and field data. HerbiGuide has collated much of this material and provided the platform for distribution.

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Project No.: CRC and GRDC DAW356

Paper reviewed by: Vanessa Stewart

Inter-row weed control in wide row lupin using knockdown-based tank mixes

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KEY MESSAGES

In response to the rapid increase in the development of glyphosate resistance in annual ryegrass, farmers should reduce the use of glyphosate for inter-row weed control in wide row lupin crops. Paraquat + diquat or paraquat + diquat + carfentrazone-ethyl provided the same or higher weed control and grain yield as glyphosate. Propyzamide banded behind the seeder as an alternative to simazine controlled annual ryegrass by 68%. Use of herbicides from alternative mode of action to control weeds in wide row lupins should reduce pressure on glyphosate and minimise the risks of developing glyphosate resistance in annual ryegrass.

AIMS

A recent survey by WAHRI (UWA) on herbicide resistance indicated that more than 65% of annual ryegrass populations in the central and northern wheatbelt have Group A and B resistance and 35% of paddocks have Group B resistant radish. This has led growers to control weeds by spraying non-selective herbicides between the rows of lupin grown in wide rows. In Australia, 55 populations of glyphosate-resistant ryegrass have been reported including five in WA. The National Glyphosate Sustainability Working Group (GSWG) has identified wide row cropping system as a risky practice for the development of glyphosate resistance. One way to minimise this risk is to apply paraquat + diquat or knockdown-based herbicide mixtures in wide row lupin systems.

The aim of this study was to evaluate the efficacy of inter-row and on-row weed control options in wide row lupin crops using herbicide mixtures to reduce pressure on glyphosate.

METHOD

Lupin, cv. Mandelup, was sown at 120 kg/ha on 4 June into wheat stubble using a commercial seeder (John Deere TVT) that spread seed within rows over a band of 10-12 cm. The distance between rows (row spacing) was variable (750-850 mm around the wheel, flanked by 640 mm on the wing, with the central three rows at 400 mm) but the average row spacing was about 650 mm (actual average inter-row width was 500 mm). The unit plot size was 12 m x 20 m. At sowing, 100 kg/ha of fertiliser including 80 kg double phosphate, 10 kg muriate potash and 10 kg sulphate of potash was applied. Glyphosate 650 g a.i./ha and 2,4-D ester 240 g a.i./ha was sprayed four days before sowing and paraquat + diquat 500 g a.i./ha immediately before sowing. Some big size radish plants were transplanted into the lupin crop though. Simazine 1.1 kg a.i./ha was sprayed before sowing (treatment 1 to 6) on 4 June 2006. Propyzamide 500 g a.i./ha was sprayed in a 20 cm band over lupin rows at sowing time (treatment 8 to 12) on 4 June 2006. Initial density of lupin and annual ryegrass plants was counted on 1 August 2006. Inter-row spray-shield treatments and the tank mix of diflufenican + carfentrazone-ethyl applied to the base of lupin plants were sprayed on 28 August. Clethodim and metosulam were sprayed two weeks before inter-row spraying. Heads of the surviving annual ryegrass plants and final density of wild radish were counted on 16 October. Weed control percentage in the treatments was determined by comparing with untreated control plots in each block. The crop was harvested on 13 November 2006.

Treatments

The treatments were laid out in randomised complete block design with three replications:

1. Simazine 1 kg a.i. PS1/clethodim 60 g a.i./metosulam 5 g a.i. all over plot (i.e. Farmer's control).
2. Simazine 1 kg a.i. PS/glyphosate 640 g a.i. BR2.
3. Simazine 1 kg a.i. PS/paraquat + diquat 375 g a.i. BR.
4. Simazine 1 kg a.i. PS/glyphosate 640 g a.i. BR/paraquat + diquat 275 g a.i. (2 days interval) BR.

5. Simazine 1 kg a.i. PS/paraquat + diquat 375 g a.i. + carfentrazone-ethyl 18 g a.i. (tank mix) BR.
6. Simazine 1 kg a.i./ha PS/glyphosate 640 g a.i. + carfentrazone-ethyl 18 g a.i. (tank mix) BR.
7. Band propyzamide 1 kg a.i. OR/clethodim 60 g a.i. all over plot/diflufenican 100 g a.i. + metribuzin 112 g a.i. (tank mix) with oil OR3.
8. Band propyzamide 1 kg OR/glyphosate 640 g a.i. BR/diflufenican 100 g a.i. + metribuzin 112 g a.i. (tank mix) with oil OR.
9. Band propyzamide 1 kg OR/paraquat + diquat 375 g a.i. BR/diflufenican 100 g a.i. + metribuzin 112 g a.i. (tank mix) with oil OR.
10. Band propyzamide 1 kg OR/glyphosate 640 g a.i. BR/paraquat + diquat 375 g a.i. (2 days interval) BR/diflufenican 100 g a.i. + metribuzin 112 g a.i. (tank mix) with oil OR.
11. Band propyzamide 1 kg OR/Spray.Seed® 1.5 L + carfentrazone-ethyl 18 g a.i. (tank mix) BR/diflufenican 100 g a.i. + metribuzin 112 g a.i. (tank mix) with oil OR.
12. Band propyzamide 1 kg OR/glyphosate 640 g a.i. + carfentrazone-ethyl 18 g a.i. (tank mix) BR/diflufenican 100 g a.i. + metribuzin 112 g a.i. (tank mix) with oil OR.
13. Untreated control.

¹PS = Pre-sowing; ²BR = Between rows (inter-row); ³OR = On-rows (Intra-row).

RESULTS

Initial crop and weed density

On average, lupin density (as assessed on 1 August 2006) was 46 plants/m² with no difference between simazine and propyzamide treatments. However, lupin establishment was generally lower than optimum due to the prevailing dry conditions after sowing. On-row ryegrass density was 70-85% lower than inter-row density (1583 plants/m²) in untreated control. Propyzamide banding reduced on-row ryegrass density by 51% compared with the on-row density of the untreated control (432 plants/m²). On average, the number of radish plants was 2.5/m² on the rows and 4.4/m² between the rows.

Table 1. Effect of on-row and between-row weed control treatments on the control of wild radish plants and annual ryegrass heads, and grain yield of lupin at the Fulwood farm, Meckering, WA in 2006*

Treatments	Weed control between rows (%)		Lupin yield (kg/ha)	Yield increase (%)	Lupin plants/m ²
	Annual ryegrass heads	Wild radish plants			
1	70	70	680	14	46
2	100	100	712	20	41
3	98	100	1180	99	49
4	100	89	616	4	50
5	97	100	857	44	45
6	97	80	628	6	38
7	88	17	1046	76	48
8	100	100	831	40	63
9	92	97	759	28	44
10	100	100	921	55	46
11	96	100	1176	98	47
12	100	100	890	50	30
13	0	0	594	0	54
Isd (p = 0.05)	14.2	28.9	277.3	-	17.1

* In the untreated control: Annual ryegrass heads between rows was 674/m² and final wild radish density between rows was 6 plants/m²; farmer's yield in this paddock was 800 kg/ha.

Final weed control

Regardless of treatment, inter-row spraying controlled 96 to 100% of annual ryegrass heads and 80-100% of wild radish plants between lupin rows compared with the untreated control. Simazine + clethodim (farmer's control) controlled 70% annual ryegrass heads between lupin rows compared with the untreated control. Within-row weed control was highly variable due to poor activity of simazine (pre-sowing) and propyzamide (on-row) caused by the prolonged dry conditions after seeding. On average, propyzamide reduced annual ryegrass heads in lupin rows by 68% compared with the untreated control. Weed control by paraquat + diquat was similar to glyphosate. Inter-row weed control by tank mixes such as glyphosate + carfentrazone-ethyl or paraquat + diquat + carfentrazone-ethyl was similar to glyphosate indicating that neither of these mixtures was antagonistic. Wild radish control by a mixture of diflufenican + metribuzin with oil on lupin rows was also variable in this trial.

Lupin grain yield

Highest grain yield (1180 kg/ha) was recorded in treatment 3 (simazine/paraquat + diquat) closely followed by treatment 11 (propyzamide/paraquat + diquat + carfentrazone-ethyl) and the lowest was in the untreated control (Table 1). Treatments 3, 7, 10 and 11 also produced significantly higher grain yields than the untreated control. Farmer's lupin yield in this paddock was 800 kg/ha. Generally, the grain yield increased by 4 to 99% over the untreated control but the grain yields were not always consistent with the level of weed control achieved. Staggered emergence and uneven establishment due to the prolonged dry conditions after sowing, the resultant variability in simazine and propyzamide activity, together with inadvertent damage of some lupin plants at the time of inter-row spraying in some plots might have contributed to the high variation in lupin grain yield.

CONCLUSION

Even though 2006 was a low rainfall year, propyzamide as a banded application on lupin rows reduced annual ryegrass head production by 68%. Inter-row spraying controlled 96 to 100% of annual ryegrass heads and 80-100% of wild radish plants between rows compared with the untreated control. Lupin yield in treatment 3 (simazine/paraquat + diquat) and 11 (propyzamide/paraquat + diquat + carfentrazone-ethyl) was significantly higher than glyphosate (treatment 2). Weed control efficacy of knockdown-based tank mixes sprayed on the inter-rows was as good as glyphosate or paraquat + diquat, although the grain yield of lupin was not always consistent with the level of weed control achieved. Staggered emergence, poor establishment of lupin, and inadvertent damage of some lupin plants in some plots at the time of inter-row spraying might have contributed to the variation in lupin yield. The results, however, show that farmers can use paraquat + diquat or paraquat + diquat + carfentrazone-ethyl instead of relying on glyphosate for inter-row spraying thus minimise the risk of developing glyphosate resistance in annual ryegrass.

KEY WORDS

glyphosate, paraquat + diquat, propyzamide, carfentrazone-ethyl, annual ryegrass, wild radish, knockdown-based tank mixes, herbicide resistance

ACKNOWLEDGMENTS

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Project No.: DAW00114

Paper reviewed by: David Ferris

Timing of weed removal in wide-row lupins

Sally Peltzer, Shahab Pathan and Paul Matson, Department of Agriculture and Food, Western Australia

KEY MESSAGES

- In a dry season like 2006, the earlier and more effective the weed removal, the less competition for soil moisture then the greater the lupin yields.
- Where weeds are susceptible to triazines, conventional treatments of simazine and atrazine followed by diflufenican and metribuzin provide about twice the yield of inter-row weeding.
- Inter-row shielded spray application of glyphosate was more effective in controlling weeds than inter-row cultivation.
- Inter-row cultivation reduced weed numbers but not weed dry matter and ultimate seed production.
- Weed species differ in their reaction to inter-row control methods.

AIMS

Wide-row lupin systems provide the opportunity to remove inter-row weeds by non-selective chemical or mechanical methods. The timing of weed removal can be important. Too early and some weed cohorts may avoid control altogether while large weeds may survive if the control method is applied too late. Due to the low level of competitive pressure by the crop in the inter-row, the remaining weeds can grow very large and set sizeable numbers of seed.

The critical periods of weed removal vary with species. In Western Australia, many of the grass weeds including barley grass, annual ryegrass and wild oats tend to emerge in the first month of the season break, while some broadleaved weeds such as wild radish germinate throughout. This work compares mechanical and chemical control of inter-row wild radish and capeweed on the growth and yield of narrow-leaved lupins.

METHODS

A site was selected at Wongan Hills with a background of wild radish and capeweed. The site was pre-treated with a double knockdown (glyphosate followed two days later by paraquat/diquat) then sown to Mandelup lupins in 50 cm wide rows on 29 May 2006. The trial had a randomised block design with three replicates. Mechanical and chemical inter-row-only weed control was compared with a conventional broadcast chemical spray (2 L/ha simazine plus 2 L/ha atrazine IBS followed by 100 mL/ha Brodal™ and 150 g/ha Metribuzin™ post-emergent). The inter-row treatments were undertaken at three times during the season (4-leaf stage, 10-leaf stage and flowering stage of the lupin or Weed Removal Times 1, 2 and 3) either by cultivating at 5 cm with an adjusted 3-point linkage Massey Ferguson Scarifier or with shielded sprays applying 2 L/ha glyphosate. A control was included where there was no weed control except for the pre-seeding knockdown.

RESULTS AND DISCUSSION

In a very dry year, such as 2006, it was imperative to conserve all of the soil moisture for lupin production. In this trial, the conventional broadcast treatment resulted in the highest yields compared to all the inter-row treatments (Figure 1, $p < 0.05$). The broadcast treatment allowed the weeds to be removed early and the combination of the continuing action of the triazines with the post-emergent herbicide application further suppressed weed germination. Later in the season, the shielded spray treatments at Weed Removal Times 2 and 3 were very successful in controlling the weed burden (Figure 2), however, but this eventuated in low lupin yields. This occurred especially when the weeds were removed at lupin flowering (or Weed Removal Time 3), indicating that weed competition was responsible. None of the inter-row cultivation treatments differed from the control in their eventual lupin production.

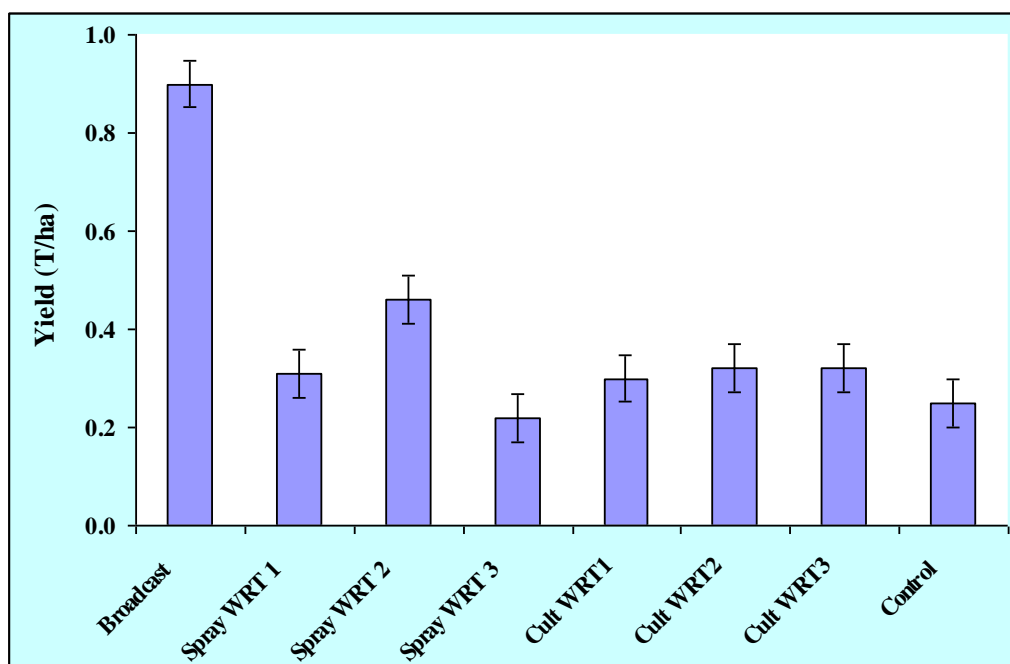


Figure 1. The effect of weed removal method (Broadcast, inter-row shielded sprays (Spray) and inter-row cultivation (Cult)) and timing (Weed Removal Times (WRT) 1, 2 and 3) on the yield of narrow leaved lupins. Mean of 4 replicates.

Although there was little difference in the eventual yields within the inter-row treatments, the weed dry matter production and numbers did differ with the timing and type of inter-row weed removal. Inter-row glyphosate application was generally more successful at reducing weed numbers and dry matter than inter-row cultivation (Figure 2) as was weed removal at Weed Removal Time 2.

There were two significant rainfall events at Wongan Hills in late July and mid-August (> 20 mL combined and 8-10 weeks after planting). These resulted in substantial increases in both wild radish and capeweed emergence between the 4-leaf and the 10 leaf stages of the lupin (or between Weed Removal Times 1 and 2). Subsequently, early inter-row cultivation or glyphosate application (at Weed Removal Time 1) failed to control the weed burden, culminating in high levels of weed dry matter at lupin flowering and reduced lupin yields (Figures 1 and 2, $p < 0.05$). Cultivation at Weed Removal Time 1 actually increased wild radish numbers (over 50%, $p < 0.05$) above the control, possibly due to a stimulation of germination by tillage. Cultivation did not stimulate capeweed emergence and seemed to slightly reduce the numbers (not statistically significant) compared to the control. This could have been due to a seed burial effect. It is important to understand the effect of tillage on different weed species. Wild radish can be stimulated by cultivation by redistributing seed to a more favourable environment or by damaging the seed pod and allowing germination (Newman *et al.* Crop Updates, 2007). Other species stimulated by tillage include annual ryegrass and doublegee (Peltzer and Matson, Crop Updates, 2002). Conversely, burial inhibits germination of capeweed due to the small size of the seed and its' ability to undergo dormancy cycling (Dunbabin and Cocks, 1999).

Shielded spray application at Weed Removal Time 2 resulted in over 99% weed control. As a consequence, weed dry matter was reduced (Figure 2) but due to the dry season, only marginal increases in lupin yields compared to the broadcast treatments were realised due to the likely competition for water. Inter-row cultivation at Weed Removal Time 2 (lupin 10-leaf stage), reduced the wild radish numbers by over 50% ($p < 0.05$). The remaining, or transplanted weeds however, grew substantially, filling the inter-row and producing similar dry weights to the untreated control. There were reduced lupin yields (Figure 1) and a high radish seed production.

Inter-row cultivation and glyphosate application at flowering was successful in removing the weed burden but did not increase yields. The lupin plants within these treatments as well as the control, had already substantially hayed off compared to the earlier weed removal treatments.

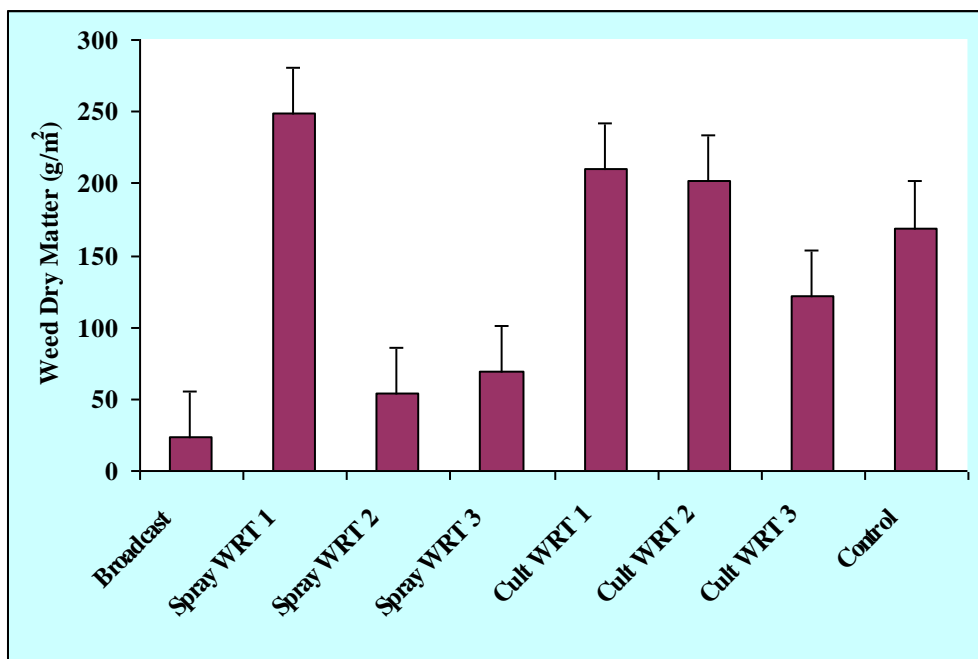


Figure 2. The effect of weed removal method (Broadcast, inter-row shielded sprays (Spray) and inter-row cultivation (Cult)) and timing (Weed Removal Times (WRT) 1, 2 and 3) on the weed dry matter at lupin flowering. Mean of 4 replicates.

CONCLUSION

In a dry season, weed control methods need to be applied early in the season to prevent competition with soil moisture. Care must be taken also, when considering the timing of weed control and the possible effect of tillage on the weed species present.

It is imperative that there are high levels of weed control in wide-row situations. A germination after inter-row treatment or inadequate control at the right time can result in weeds remaining. Without competition, these weeds continue to grow and can eventually set large numbers of seeds. With herbicide resistance, these weeds then become next year's nightmare.

KEY WORDS

lupins, wild radish, capeweed, wide-row

ACKNOWLEDGMENTS

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Paper reviewed by: John Moore

The effects of row spacing and crop density on competitiveness of lupins with wild radish

Bob French and Laurie Maiolo, Department of Agriculture and Food, Western Australia, Merredin

KEY MESSAGES

Lupins are more competitive with wild radish at high than at low crop densities. However, even at densities above 100 lupin plants/m² wild radish can reduce lupin grain yield by up to 40% and is able to set significant amounts of seed if it is not controlled.

Lupin row spacing had no clear effect on competitiveness with wild radish. Any effect was only at crop densities of 80 plants/m² and above.

Growers should keep lupin densities above 40 plants/m² to minimise competition from wild radish but this will only be a small part of integrated weed management for wild radish in lupins.

BACKGROUND

The increasing prevalence of herbicide resistance in important weeds of lupins means that integrated weed management (IWM) packages are becoming increasingly important for lupin growers. Since lupins have a reputation for not being a very competitive crop we have been searching for ways to make them more competitive. Increasing lupin row spacing from 20 to 60 cm reduces lupin competitiveness against annual ryegrass, but raising crop density increases it (French and Maiolo 2006). We describe here a trial designed to investigate the effect of row spacing and crop density on the competitiveness of lupins with wild radish.

METHOD

Mandelup lupins were sown in 25 or 50 cm rows at crop densities of 0, 10, 20, 40, 80, or 120 plants/m² at Wongan Hills Research Station on a site with a background population of wild radish. The trial was sown on 29 May but emergence was delayed by dry conditions during June. Half of the plots were sprayed with Brodal after radish seedlings emerged to give weed-free control treatments. There were two 50 cm row treatments: In one the plots were cultivated at seeding halfway between the rows by the seeding tines; in the other the inter row was left undisturbed.

RESULTS

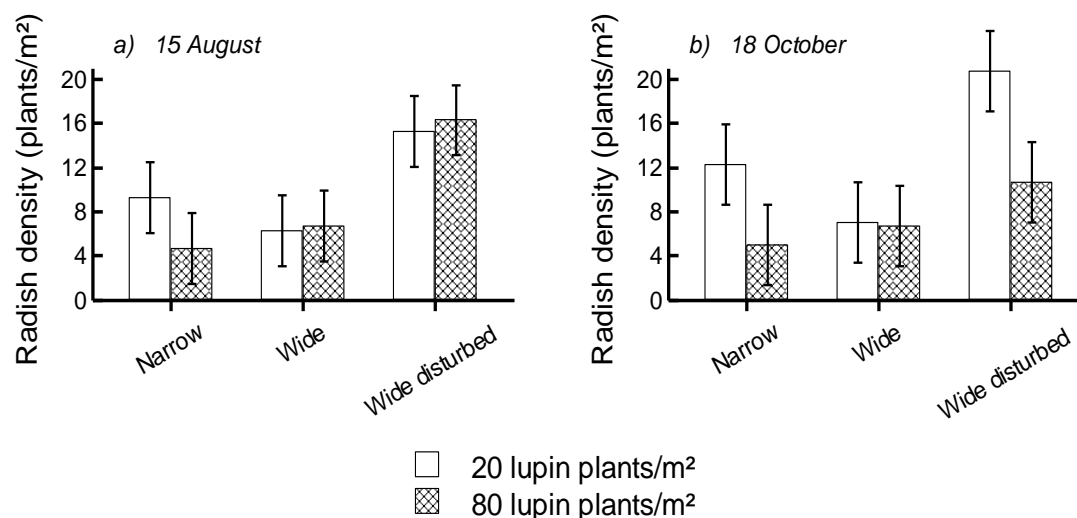


Figure 1. Effects of row spacing and crop density on wild radish density in lupins at Wongan Hills on two different dates in 2006. Vertical bars indicate lsd at P = 0.05.

Average wild radish density across the site in treatments not sprayed with Brodal was 10-11 plants/m², and in the Brodal treatments was less than 1 plant/m². Neither row spacing nor crop density had any significant effect on wild radish density, nor on the survival of wild radish plants from mid-August to crop maturity (Figure 1). Wild radish density was quite variable across the site – Figure 1 gives the impression that the wide disturbed treatment had a higher radish density than the wide and narrow treatments, but this was not statistically significant.

Row spacing had no effect on wild radish biomass production, but increasing crop density reduced it dramatically. There was only about a third as much wild radish present when the lupin density was 120 plants/m² as when there were no lupins (Figure 2). There seemed to be more suppression of wild radish growth in narrow compared to wide rows at high crop density than at low density, but it is difficult to be sure given the variability of the data.

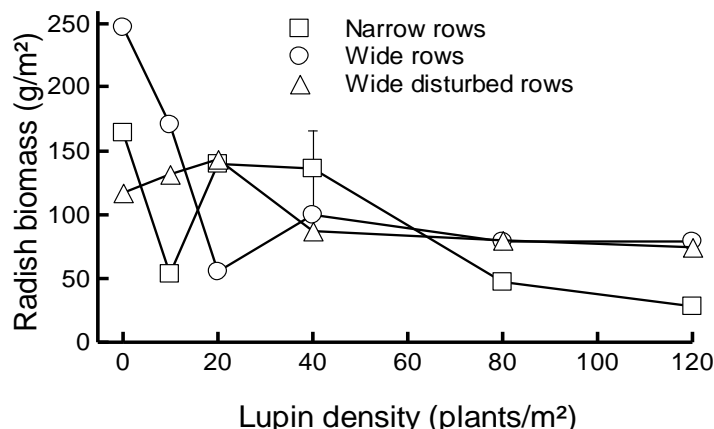


Figure 2. Dependence of wild radish biomass on lupin plant density. Measurements made on 18 October 2006. Vertical bar indicates lsd at $P = 0.05$.

Competition from wild radish suppressed lupin growth less at high than at low lupin densities (Figure 3). This was also reflected in grain yield which continued to increase with density to higher densities in the presence of wild radish than in its absence (Figure 4). Competition from wild radish reduced lupin yield by 54% when crop density was 20 plants/m², but only by 44% when it was 80 plants/m². And lupin yield was higher at 80 than at 20 plants/m² in the absence of wild radish as well. Row spacing did not influence lupin biomass production or grain yield in this trial.

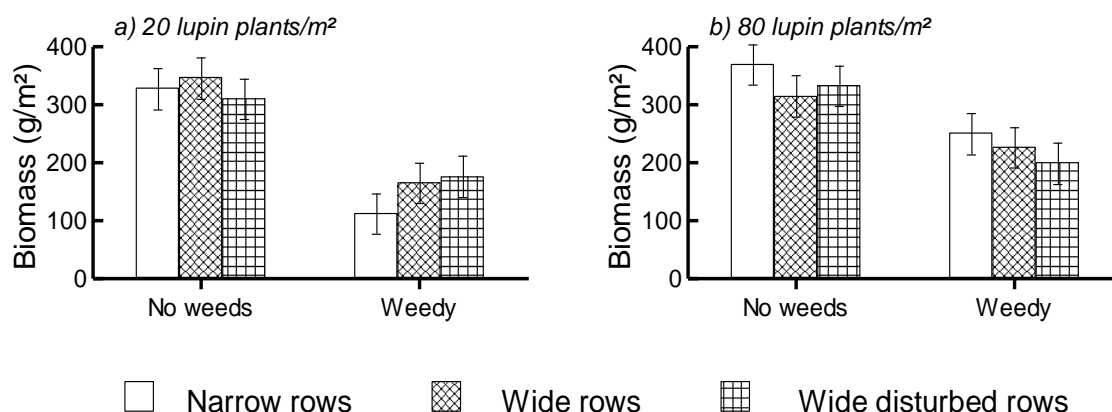


Figure 3. Effects of row spacing and competition from wild radish on maximum biomass production by lupins at two different densities at Wongan Hills in 2006. Measurements made on 18 October 2006. Vertical bars indicate lsd at $P = 0.05$.

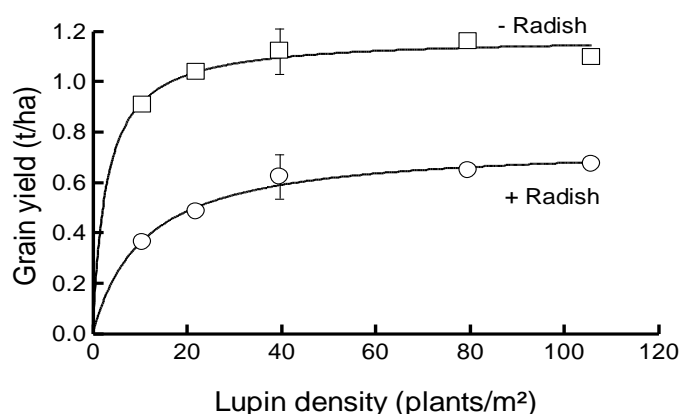


Figure 4. Lupin grain yield response to crop density in the presence and absence of competition from wild radish. Vertical bars indicate lsd at $P = 0.05$.

Row spacing might be expected to affect the spatial distribution of weeds. In particular, the greater intensity of interplant competition within wide compared to narrow rows might suppress weeds close to the row more than ones further away. Figure 5 shows that neither row spacing nor proximity to the row had any effect on wild radish biomass measured at maximum crop biomass. There was actually more radish growing close to the rows than would be expected if it was evenly distributed according to plot area: The proportion of total radish biomass growing within 5 cm of the crop rows was 0.59, 0.40 and 0.48 respectively for narrow, wide and wide disturbed rows, compared to expected values of 0.4, 0.2 and 0.2.

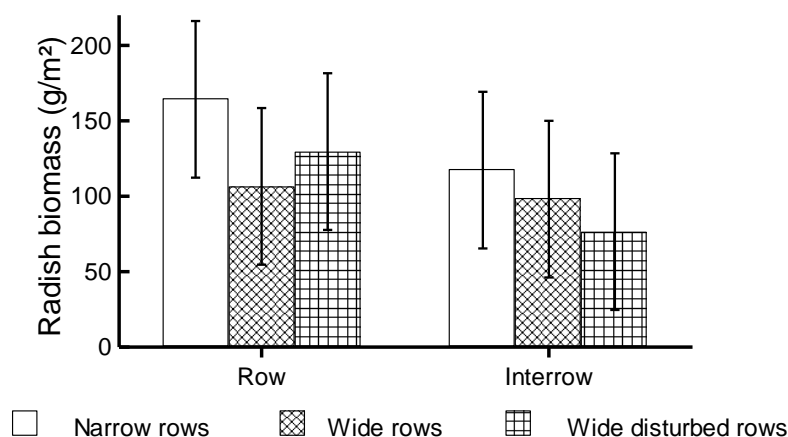


Figure 5. Biomass of wild radish plants within 5 cm of the lupin row (Row) or further away (Interrow) on 18 October 2006. Vertical bars indicate lsd at $P = 0.05$. Data are presented for 40 plants/m² density treatment only.

CONCLUSION

An average wild radish population of 10-11 plants/m² caused a large reduction in lupin yield. The yield reduction was smaller at high than at low crop density, but even at more than 100 lupin plants/m² the yield reduction was about 40%. The greater competitiveness of dense treatments also suppressed wild radish growth, which would lead to less wild radish seed being carried over into the next rotational phase, but substantial amounts of wild radish were present even at very high crop densities. This means that lupin crop competitiveness cannot be increased sufficiently, at least not by manipulating crop density or row spacing, to replace chemical means of wild radish control. But keeping crop densities above 40 plants/m² could minimise the severity of wild radish blowouts, and may be helpful in conjunction with other components of an integrated weed management strategy.

Row spacing had no clear effect on the competitiveness of lupins with wild radish, except that at high densities crop densities lupins in narrow rows appeared more competitive than lupins in wide rows. There was no effect of the position of wild radish plants in relation to crop rows on how much

competition they experienced from the crop at the plant densities normally recommended for lupin crops, even in wide rows that would have resulted in denser rows. The fact that a high proportion of radish biomass can be very close to the crop row may have implications for systems for controlling wild radish by interrow spraying in wide row crops.

KEY WORDS

lupin, crop density, row spacing, radish, competition, weed management

ACKNOWLEDGMENTS

Chris Matthews, Shari Dougall and other Wongan Hills RSU staff for managing the trial.

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Project No.: DAW00099

Paper reviewed by: Dr Shahab Pathan

Is delayed sowing a good strategy for weed management in lupins?

Bob French, Department of Agriculture and Food, Western Australia, Merredin

KEY MESSAGES

The simulated median yield penalty for delaying lupin sowing for one week after the break of the season is equivalent to the yield loss caused by competition from 20 to 68 ryegrass plants/m² or 1 to 3 radish plants/m².

Expected weed densities need to be at least this high to make delaying sowing for weed control a worthwhile strategy if grain yield maximisation is an important criterion.

The expected yield penalty for delayed sowing was smaller at Mingenew than at Buntine or Merredin, so the improvement in weed control necessary to compensate for the yield penalty is not as great at Mingenew.

There may be other benefits from improved weed control that make delaying sowing worthwhile.

There is a significant risk of not getting a second sowing opportunity one week after the break of the season.

BACKGROUND

Dry sowing lupins has been a widespread practice in Western Australia. Its strengths include ensuring the crop germinates when the season breaks and that sowing lupins does not interfere with sowing other crops. However, it is a strategy that heavily depends on in-crop herbicides for weed control. It served the industry well when cheap effective selective herbicides were available for the major weeds of lupins, although it did encourage herbicide resistance to develop in these weeds. Now cheap effective herbicides are no longer available and we wish to delay resistance to our remaining herbicides developing for as long as possible. Is dry sowing still appropriate?

Department of Agriculture and Food officers have recently been encouraging growers to plant lupins into moist soil, which improves the activity of pre-emergent simazine, and even to delay sowing for up to a week following the break, which allows weeds germinating during this time to be controlled by non-selective methods (Harries and Walker 2007a). But any improvement in weed control must be traded off against reduced yield potential, the fact that you may want to sow other crops at the same time, and the risk that the soil may be too dry to sow into after the delay.

In this paper I model the yield penalty for delaying sowing after the break at Merredin, Buntine and Mingenew, and compare this to yield reductions expected from competition with wild radish and annual ryegrass. I also model the likelihood of missing a second sowing opportunity at these locations.

METHOD

Lupin yields were simulated using APSIM 4.2, with some parameter modifications based on my unpublished data, for each year from 1901 to 2004 at Merredin and Mingenew, and from 1930 to 2004 at Buntine. I used weather data from the patched-point dataset maintained by the Queensland Department of Natural Resources and Mines. Soil properties at Merredin and Mingenew were based on my unpublished data, and at Buntine on those supplied with APSIM. Three types of simulation were run. For the first two Mandelup lupins were sown on the break or seven days later. The break in this context is the first day between 15 April and 15 June when there was at least 5 mm extractable soil water in the top 5 cm of soil, and at least 10 mm in the top 20 cm. The third simulation identified as the next sowing opportunity by waiting seven days after the break and then choosing the first day when the same soil moisture criteria were satisfied.

The effects of weed competition were analysed using the following equation:

$$(1.1) \quad Y = \frac{Y_0}{(1 + \beta x)}$$

where Y is crop yield, Y_0 is yield in the absence of weeds, x is weed density, and β is a competition coefficient. The value of β for wild radish was derived from data of Harries and Walker (2007b) and Pathan *et al.* (2006), and for annual ryegrass from my own unpublished data and other data from C. Zaicou.

RESULTS AND DISCUSSION

Simulating sowing time response

Yield potential was much higher at Mingenew than at Buntine or Merredin (Table 1) and the yield penalty for delayed sowing was also smaller, both in absolute and relative terms. The figures in Table 1 are summarised as medians, but they come from rather skewed distributions: Figure 1 shows the distributions of yield for Merredin.

Table 1. Median values for lupin yield when sown on the break and one week after the break, yield penalty for delaying sowing a week, and days until the next sowing opportunity after the break, ignoring opportunities within one week. Note that the median yield penalty is not the same as the difference between the median yields on the break and one week after. This arises because of the very skewed distribution of yield penalties

	Yield on break (kg/ha)	Yield 1 week after break (kg/ha)	Yield penalty (kg/ha)	Days to next sowing opportunity
Mingenew	3.08	2.78	0.12	14
Buntine	1.50	1.39	0.20	18
Merredin	1.50	1.34	0.18	10

Yield reduction from weed competition

Figure 2 shows how yield responded to wild radish density in two experiments (Pathan *et al.* 2006, Harries and Walker 2007) with curves described by equation (1.1) fitted. The values of β for wild radish derived from these data ranged from 0.015 to 0.096, with a mean of 0.056. The mean value for annual ryegrass from one of my unpublished trials and a trial of C. Zaicou was 0.0022. Subtracting equation (1.1) from Y_0 and rearranging gives the following expression for the yield penalty ΔY :

$$(1.2) \quad \Delta Y = Y_0 \left(\frac{\beta x}{1 + \beta x} \right)$$

Table 2. Wild radish and annual ryegrass densities that would cause the same yield loss as delaying sowing by one week at three locations in the wheatbelt. These were calculated using the median yield penalties given in Table 1 and equation (1.2)

	Wild radish (plants/m ²)	Annual ryegrass (plants/m ²)
Mingenew	0.7	19
Buntine	2.7	68
Merredin	2.4	62

Using the mean values of β we can calculate the weed density that would cause the same yield loss as delaying sowing by one week. Table 2 shows that the yield penalty for a one week sowing delay is about the same as the yield loss (1.2) predicts would be caused by competition from 19 to 68 ryegrass plants/m², or 1 to 3 radish plants/m². The equivalent weed densities are higher at Merredin and Buntine than at Mingenew.

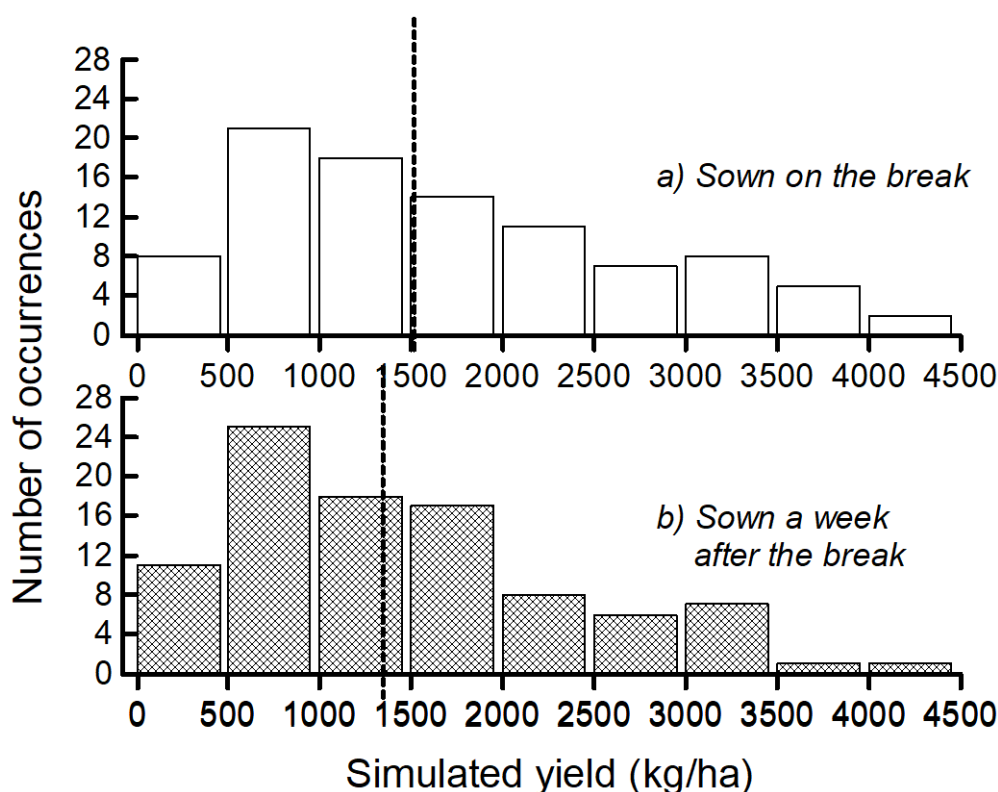


Figure 1. Distribution of simulated lupin yields from 1901 to 2004 at Merredin when sown on the break of the season or a week after the break. Dotted lines show the median value.

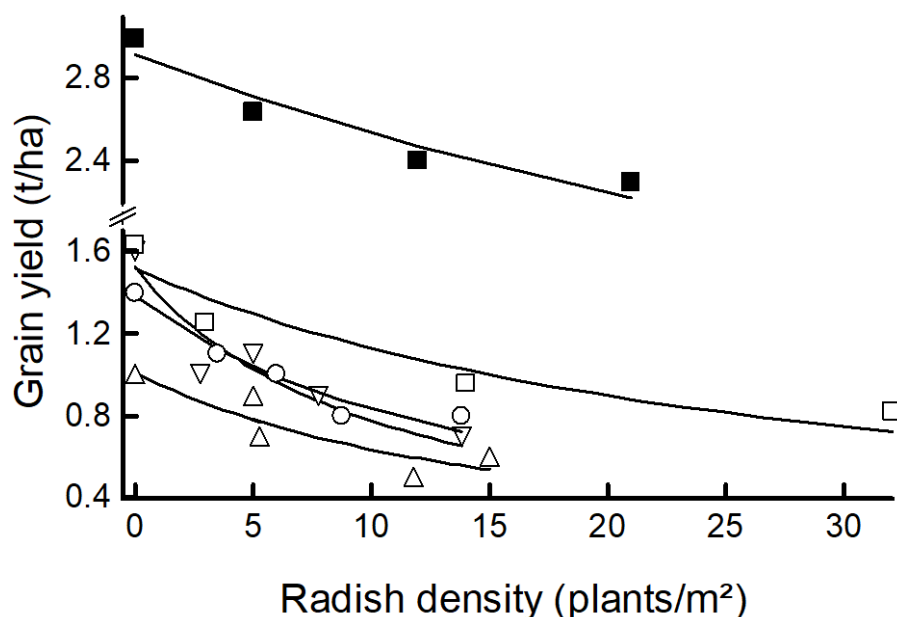


Figure 2. Fitted response curves (equation (1.1)) of yield loss in Mandelup lupins as a function of wild radish density. Square symbols show data from Pathan *et al.* (2006) and other symbols from Harries and Walker (2007b).

DISCUSSION

To compensate for the reduced yield potential due to delaying sowing for a week would require ryegrass densities to be reduced by at least 60 plants/m², or radish densities by at least 2 plants/m², in low rainfall areas, so if background weed burdens are not at least this high reduced competition will not compensate for the loss of yield potential from delayed sowing. When selective herbicides are still effective it is difficult to imagine ryegrass control improvements of this magnitude from delayed sowing,

but it is realistic to expect radish control improvements of this magnitude. The necessary improvement in weed control at Mingenew is much smaller: Less than 20 ryegrass plants/m² and less than 1 radish plants/m² and should often be achievable.

There may be other benefits of improved weed control apart from removing competitive effects on grain yield. There may be savings in costs of selective herbicides and, perhaps more importantly, reduced weed seed production leading to lower weed burdens in following crops. These would need to be considered in a completely rigorous analysis of the value of delayed sowing as a weed management tool.

There are also other risks associated with delaying sowing apart from reduced yield potential. A major one is the risk that seedbed conditions will not be suitable a week after the break. Even at Mingenew there was a 50% chance that a second sowing opportunity would not occur until more than two weeks after the break, and at Buntine until nearly three weeks after the break. Surprisingly, the likelihood of a long delay until the second sowing opportunity was no greater at Merredin than at Mingenew. You might therefore be more wary about delaying sowing to manage weeds at Buntine than at Merredin or Mingenew.

How dependant these results are on the particular definition of the break and the next sowing opportunity is not clear. It may be rash to only require 10 mm soil moisture for a break in mid-April, and it may be over-restrictive to require 5 mm in the top 5 cm of the profile for a second sowing opportunity. However, alternative scenarios could easily be analysed using the framework outlined here.

KEY WORDS

lupin, sowing time, APSIM, wild radish, annual ryegrass, competition

ACKNOWLEDGMENTS

Bill Bowden made helpful comments on a draft of this paper and Christine Zaicou allowed me to use her data on ryegrass competition with lupins.

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Project No.: DAW00099

Paper reviewed by: Martin Harries

Delayed sowing as a strategy to manage annual ryegrass

Bob French and Laurie Maiolo, Department of Agriculture and Food, Western Australia, Merredin

KEY MESSAGES

Delaying lupin sowing for nine days after the break of the season at Merredin in 2006 did not reduce annual ryegrass density, presumably due to the soil surface drying out rapidly after the break so that few weeds germinated before the second sowing.

The yield penalty for delayed sowing was greater when the weed burden was high than when it was low.

Mandelup and Belara lupins were more competitive against annual ryegrass than Tanjil lupins, and they suffered a smaller yield penalty for delayed sowing.

Relying on delayed sowing to improve weed control is a risky strategy at Merredin because of the likelihood of little weed germination in an acceptable time period following the break.

BACKGROUND

The development of widespread resistance to selective herbicides in weeds such as annual ryegrass has meant that lupins have changed from being a phase in the rotation where growers can dramatically reduce grass numbers to one where grass numbers can increase catastrophically. This is because lupins are not very competitive against weeds, and because the strong emphasis on sowing them early places heavy reliance for weed control on selective herbicides, which may fail. One means that has been suggested for reducing the reliance on selective herbicides at the same time as minimising weed build-up in lupin phases of rotations is to delay sowing for up to a week after the season breaks. This is supposed to allow a first flush of weeds to germinate which can then be controlled with non-selective herbicides prior to sowing. Such a strategy involves a trade-off between the reduced yield potential delaying sowing entails and the higher yield due to reduced weed competition. Reduced weed seed set is another benefit. This trade-off implies that it would be a more valuable strategy in high weed than low weed backgrounds.

The trial described in this paper was designed to test whether delaying sowing would reduce ryegrass numbers sufficiently to compensate for the loss in yield potential due to delayed sowing, and to compare the response in low and high weed backgrounds.

METHOD

In October 2005 sections of a weedy wheat crop were sprayed out with 2 L/ha Roundup to prevent weed seed set. These areas became the low weed burden treatments in 2006 while unsprayed areas became the high weed burden treatments. In 2006 Mandelup, Belara, and Tanjil lupins were sown on 17 May, the day after 17 mm rain fell. The second sowing date was on 26 May, 2 days after 30 mm rain fell. 2.0 L/ha Spray.Seed® and 2.0 L/ha Simazine were applied prior to each sowing and the site had previously been sprayed with Roundup® Power Max, Garlon DS® and Hammer® to control wild radish that had germinated in the wet summer. The only post-emergent herbicide applied was Brodal®, until half of each plot was crop-topped with 800 mL/ha Gramoxone® on 16 October.

RESULTS

Seed set control in 2005 had a large effect on ryegrass density. On 21 July the average density in low weed burden treatments was 14 plants/m², compared to 43 in high weed burden treatments. Cultivar and sowing time had no effect on weed density at this stage.

By 7 October, the delayed sowing treatment actually contained a greater density of ryegrass plants than lupins sown on the break (Figure 1a). However, ryegrass plants in the delayed sowing treatment were smaller than in lupins sown on the break and there was no effect of sowing time on the density of ryegrass heads at this stage. There were significantly more ryegrass heads in Tanjil than in Belara or Mandelup though (Figure 1b).

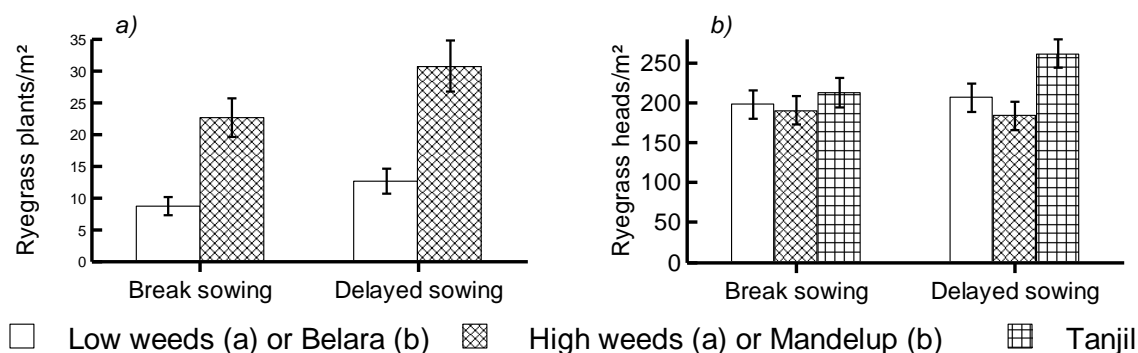


Figure 1. Effects of seed set manipulation in 2005 and delayed sowing on ryegrass density in lupins (a) and effects of cultivar and delayed sowing on ryegrass head number (b). Vertical bars indicate Lsd at P = 0.05. Measurements made on 7 October 2006.

Competition from ryegrass significantly reduced lupin biomass production (Figure 2a) but there was no interaction with cultivar or sowing time. Mandelup and Belara produced more biomass than Tanjil though, especially in the delayed sowing treatment. Delaying sowing did not have a significant effect on ryegrass biomass at crop maturity, but there was less ryegrass biomass in Mandelup and Belara than in Tanjil (Figure 2b).

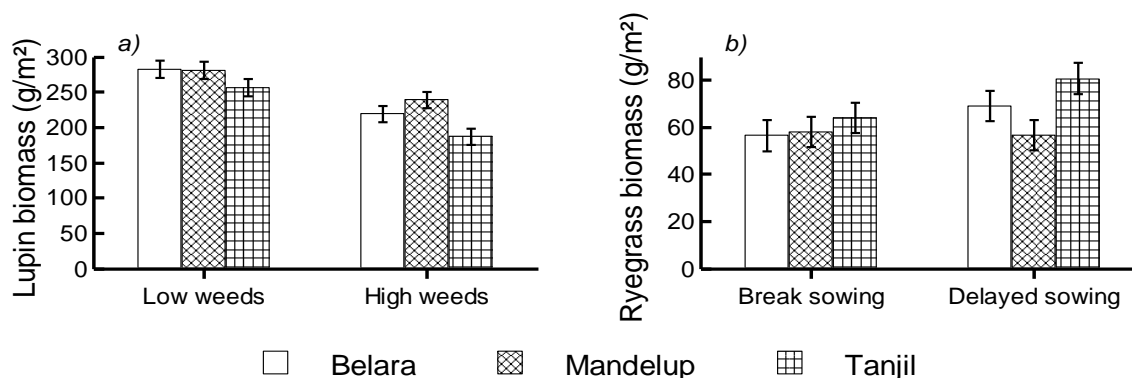


Figure 2. Effects of cultivar and weed burden on lupin biomass (a) and of cultivar and delayed sowing on ryegrass biomass (b). Vertical bars indicate Lsd at P = 0.05. Measurements made at crop maturity.

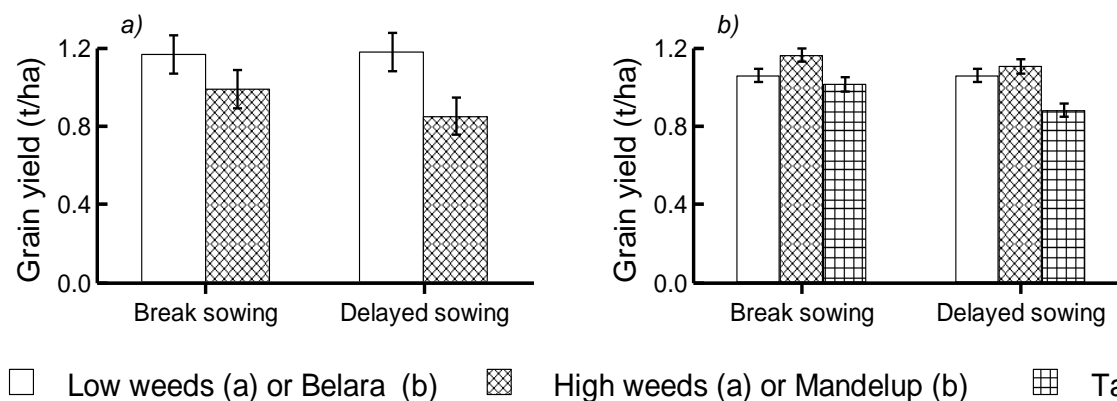


Figure 3. Effects of delayed sowing and weed burden (a) and delayed sowing and cultivar (b) on lupin grain yield. Vertical bars indicate Lsd at P = 0.05.

In this trial delaying sowing for a week after the break had no effect on grain yield under a low weed burden, but resulted in a 138 kg/ha yield penalty under a high weed burden (Figure 3a). Grain yield in the early maturing cultivars Belara and Mandelup was insensitive to delayed sowing, but the later maturing Tanjil suffered a significant yield penalty (Figure 3b). Crop topping had no effect on grain yield in this trial. Only incomplete data on ryegrass seed production were available when this paper was prepared. They show, as expected, large effects of weed burden and crop-topping, but any effects of delaying sowing or cultivar are not clear. We hope they will become clearer when sample processing is complete.

DISCUSSION

The strategy of delaying sowing lupins to improve weed control did not work in this trial, emphasising the risky nature of the strategy. Delaying sowing for nine days led to no reduction in weed density and, in fact, by the end of the season there may have been more ryegrass in the delayed sowing treatments, suggesting that delaying sowing reduces the competitiveness of lupins against ryegrass. The lack of any improvement in weed control is probably due to there being no follow-up rain after the first sowing until two days before the second sowing, leaving the soil surface dry most of this time so that there was little opportunity for weeds close to the soil surface to germinate. Alternatively, the summer rain experienced in 2006 followed by dry weather in April and early May may have induced abnormal dormancy in the ryegrass that prevented it from germinating in the week following the break (S. Pathan, pers. comm.).

Because weed control did not change, there was a yield penalty for delayed sowing in the high weed burden treatment, but not in the low weed burden treatment. This is the opposite of what we expected to find, and would mean that a grower following our strategy would have lost money. These results do not mean that delaying sowing for a week after the break during May carries no yield penalty in a weed-free situation. The crop modelling described in French (2007) shows that yield penalties for lupins can be close to, or sometimes even less than, zero. This does not happen often, but it is likely that seed bed conditions similar to those experienced at Merredin in 2006 will occur frequently, and that relying on a short sowing delay to improve weed control is a risky business. How often favourable seedbed conditions for weed germination occur after the break, and for how long, and whether this varies appreciably between wheatbelt locations, are questions that could best be answered using crop modelling, as long as those favourable conditions are clearly specified. Another risk of the strategy of delaying sowing to improve weed control is that seed bed conditions might not be suitable for sowing a week after the break, and that the grower might be forced into a much longer sowing delay than a week, which will entail a much larger yield penalty (French 2007).

There were some interesting differences between cultivars. The data on ryegrass biomass showed that Tanjil was less competitive against annual ryegrass than Belara or Mandelup. Data on lupin biomass and grain yield also pointed in this direction, but the effects on these variables failed to reach statistical significance. Tanjil is also less competitive against wild radish than Mandelup (Pathan *et al.* 2006). Tanjil was also more sensitive than Belara or Mandelup to delayed sowing. These are other reasons to avoid Tanjil in areas without a high anthracnose risk.

KEY WORDS

lupin, sowing time, annual ryegrass, competition, weed burden, integrated weed management

ACKNOWLEDGMENTS

Leanne Young, Alan Harrod and other Merredin RSU staff for management of the trial.

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Project No.: DAW00099

Paper reviewed by: Shahab Pathan

The effect of herbicides on nodulation in lupins

Lorne Mills¹, Harmohinder Dhammu² and Beng Tan¹, ¹Curtin University of Technology, Perth and ²Department of Agriculture and Food, Western Australia, Northam

KEY MESSAGES

- Propyzamide and DOW-1 significantly reduced the dry weight of nodules in Tanjil.
- Nodule mass was correlated to foliage and root mass in most of the comparisons, but not with total nitrogen content of the foliage.
- Yield was significantly correlated to nodule dry weight in Tanjil only.

AIM

To evaluate whether herbicides reduce nodulation in lupins, as lupins being a leguminous crop contribute some biologically fixed nitrogen to the succeeding cereal crop in rotation.

METHOD

Two narrow leafed lupin varieties (Tanjil and Mandelup) were sown on 3 July 2006 at the Wongan Hills Research Station on a shallow sandy duplex soil in 3 m x 10 m plots replicated 3 times. The herbicide treatments (Figure 1) were applied randomly before crop seeding (BS), immediately post planting (IPP), 2, 4, 6 and 8 leaf stage on 2 July, 3 July, 1 August, 8 August, 18 August and 25 August 2006, respectively. Basal Simazine at 2 L/ha was applied to all treated plots except for the diuron and DOW-1 treatments.

The key months for rainfall were markedly lower in May, June and July, and it did not rain significantly enough to begin seeding until 28 June. After the trial was seeded (3 July), there was no significant rainfall until 25 July when 9.6 mm precipitation was recorded (Note: Only 5.4 mm rainfall was recorded between the two July dates.).

The trials were sampled at the budding stage on 6 September, 65 days after seeding (DAS), and then at the beginning of pod formation stage on 5 October, 94 DAS. Five representative plants were visually selected and dug from each plot. The nodules were then cut from the roots, and the foliage was separated from the root portion of each plant. A sub sample of five nodules were selected from each plot sample for dissected to determine if the nodules were biologically effective (pink = effective, green = ineffective). All portions were placed in the oven at 60°C for at least 48 hours, and then weighed afterwards. Foliage samples taken at 94 DAS were tested for total nitrogen content using a Near Infra-Red machine, and the Kjeldahl Method.

RESULTS

Samples taken 65 DAS showed no significant differences between the dry weights of nodules of two lupin varieties ($\alpha = 0.05$, $p = 0.433$) in the untreated control plots. Propyzamide significantly reduced the dry weight of nodules in Tanjil (58.2%). Simazine 4 L/ha and Brodal® + Lexone® + simazine also caused more than 40% reduction in Tanjil nodule weight, but marginally missed the level of significance ($\alpha = 0.05$, LSD = 44.0%). Sub-sampled nodules were found to be effective in all plots.

Samples taken 94 DAS also showed no significant difference in nodule dry weight between Tanjil and Mandelup ($\alpha = 0.05$, $p = 0.511$). Only DOW-1 reduced Tanjil nodule weight significantly (60.7%) as compared to its control. Nodules were found to be effective in all plots.

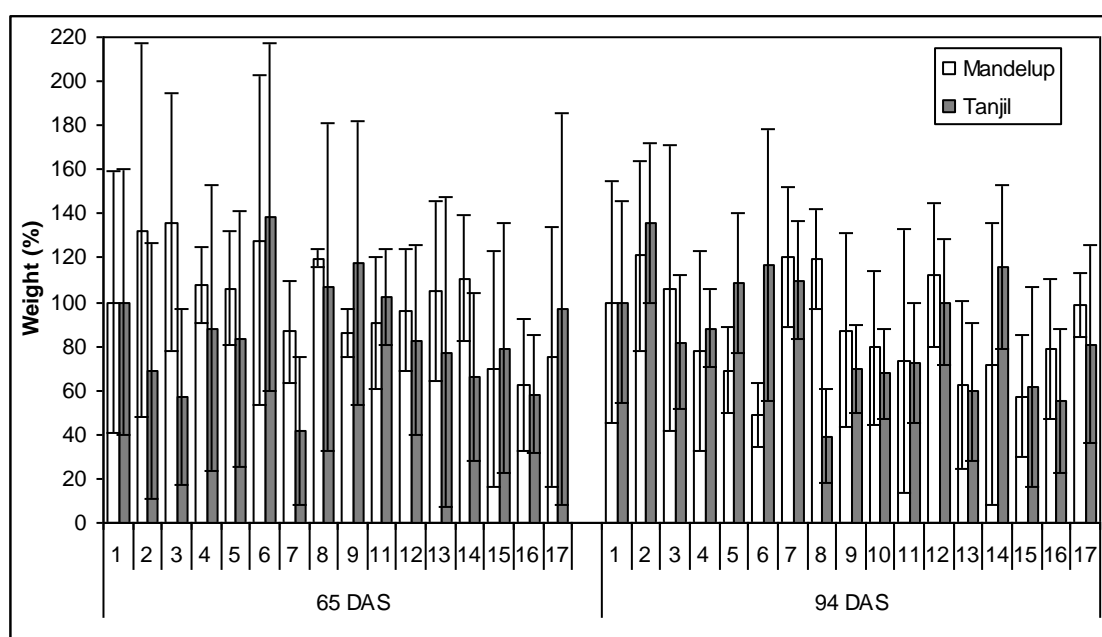


Figure 1. Comparison of nodule weights 65 DAS and 94 DAS.

(Note: Data has been scaled so that both control groups equal 100%.)

Treatments: 1-Control, 2-Simazine 2 L, 3-Simazine 4 L, 4-Diuron 3 L, 5-Simazine 2 L + Atrazine 1 L, 6-Diuron 1 L + Lexone® 133 g, 7-Propyzamide as Edge® 2 Kg, 8-DOW-1 150 g, 9-Brodal® 200 mL, 10-Sniper® 50 g, 11-Lexone® 150 g, 12-Lexone® 250 g, 13-Brodal® 100 mL + Lexone® 100 g, 14-Brodal® 100 mL + Eclipse® 6 g, 15-Brodal® 100 mL + Simazine 500 mL, 16-Brodal® 100 mL + Lexone® 150 g + Simazine 500 mL, 17-Eclipse® 10 g/ha.

Timing: 1-6 BS, 7 IPP, 8-12 at 2 leaf, 13-15 at 4 leaf, 16 at 6 leaf and 17 at 8 leaf stage.

Analysis of the nitrogen tests found no significant differences between the herbicide treatments or varieties except Sniper® reduced total nitrogen content by 8.0% in Mandelup compared to the control. Further the correlation between nodule dry weight and total nitrogen for each variety was not significant (Table 1).

Table 1. Correlations of nodule dry weight compared to foliage dry weight, root dry weight, total nitrogen and yield at 65 DAS and 94 DAS.

Sampling time	Variety	Comparison	Correlation	Significance	r (α = 0.05)
65 DAS	Mandelup	Nodule vs Foliage	0.221	Not significant	0.245
		Nodule vs Roots	0.27	Significant	
	Tanjil	Nodule vs Foliage	0.646	Significant	
		Nodule vs Roots	0.551	Significant	
65 DAS	Mandelup	Nodule vs Yield	0.04	Not significant	0.254
	Tanjil	Nodule vs Yield	0.319	Significant	
94 DAS	Mandelup	Nodule vs Foliage	0.495	Significant	0.245
		Nodule vs Roots	0.485	Significant	
	Tanjil	Nodule vs Foliage	0.553	Significant	
		Nodule vs Roots	0.526	Significant	
94 DAS	Mandelup	Nodule vs Nitrogen	-0.042	Not significant	0.285
	Tanjil	Nodule vs Nitrogen	-0.252	Not significant	
94 DAS	Mandelup	Nodule vs Yield	0.23	Not significant	0.291
	Tanjil	Nodule vs Yield	0.406	Significant	

Nodule dry weight in Tanjil was significantly correlated with foliage and root dry weights 65 DAS. However, nodule dry weight in Mandelup was only significantly correlated with root dry weight. Nodule dry weight for both Tanjil and Mandelup were correlated with the dry weight of foliage and roots of the same variety 94 DAS. Foliage and roots appeared to have the strongest correlation for both varieties at 65 DAS and 94 DAS. Yield was significantly correlated with dry weight of nodules in Tanjil only (Table 1).

DISCUSSION AND CONCLUSION

- Overseas research has indicated that herbicides can adversely affect the efficiency of legume-rhizobium symbiosis in leguminous plants, particularly nodulation processes and nitrogenase activity. Previous research with triazine herbicides have discovered that the detrimental effects are due to a decreased supply of photosynthates to the roots rather than to direct effects on nodulation and nitrogen fixation (Bertholet and Clark 1985; DeFelipe *et al.* 1987 and Kao and Wang 1981). Contrary to this, in the present study, two or three way mixes of Lexone® with Brodal® and or simazine caused significant reduction in foliage and root dry weight both in Mandelup and Tanjil 65 DAS, but there was no significant effect on dry weight of nodules.
- The rainfall pattern in 2006 season was unusual compared with previous years. The late start of the season, coupled with the lack of rain within the few weeks after seeding could have possibly negatively affected the establishment and growth of the lupins, the amount of nodulation, and also the amount of herbicide activity. Previous research has shown that soybean injury from metribuzin application increased as the level of simulated rainfall increased. It was inferred that an increase in herbicidal activity with an increase in moisture content would certainly be expected with metribuzin having a solubility of 1220 ppm (Coble and Schrader 1973; Bertholet and Clark 1985).
- Originally it was hypothesised that the application of herbicides will decrease the amount of nodulation. This was found to be partially correct, as some herbicide treatments did in fact significantly decrease nodulation. However, it was also found that some treatments increased it. Reasons for this was possibly due to some infestation of weeds pressuring lupins in the control plots, and because of the high amount of variation within the results due to unusual weather conditions (Figure 1). So overall the data did not show as many statistically significant differences as first anticipated.
- In future, to make it more practical to assess, the trial should have smaller plots with less treatments, and more samples should be taken per plot (around 10 or more). This would also make it more practical to weed the plot on a regular basis. Because the weather conditions during this trial did not represent the patterns of a 'normal' growing season, the trial should be run over several years in order to take such variability's into account.

KEY WORDS

herbicide, nodule, lupin, nitrogen

ACKNOWLEDGMENTS

Many thanks to Chris Roberts and Daphne Sargeant for their assistance with the trials. Peter Burrridge for his help with the nitrogen testing. Mario D'Antuono, who helped with the statistical analysis and GRDC for funding this project.

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Paper reviewed by: Dr Peter White

Response of new wheat varieties to herbicides

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KEY MESSAGES

- Binnu and Bullaring showed good tolerance to commonly used herbicides, similar to or better than Wyalkatchem.
- Kalka showed sensitivity to Jaguar® and Jitarning to dicamba.
- Boxer Gold and Cheetah Gold – potential new herbicides were tolerated well by all the varieties except WAWHT 2773 which seems to have low crop safety margins for Boxer Gold.
- Tank mixing diuron with Dual® seems to improve crop safety than application of Dual alone.

AIM

To evaluate the herbicide tolerance of potential and recently released wheat varieties.

METHOD

Location and year	Merredin (ME), 2006	Katanning (GS), 2006
Soil type, pH (CaCl ₂) and OC (%)	Clay, 5.0 and 1.17	Duplex sandy loam, 5.2 and not tested
Trial design	Criss-cross, every 8 th plot was untreated control.	
Plot size (Gross) and replications	10 m x 3 m, 3	10 m x 3 m, 3 EAG 2248– 5 m x 3 m, 3
Sowing date and seeding rate	8 June and 75 kg/ha	4 July and 75 kg/ha
Seeding machinery	Knife points and press wheels	Superseeder points (573 Combine)
Fertiliser	Agras No. 1 100 kg/ha	Agstar Extra Plus 100 kg/ha Urea 56.4 kg/ha – 30 August
Soil moisture (%) at seeding 0-10 cm (Gravimetric method) 10-20 cm	8.6 14.6	12.4 6.6
Herbicides application date Before seeding Z12-Z13 Z13-Z14 Z15-Z16/Z21+	7 June 28 July 17 August 21 August	3 and 4 July 16 August 16, 17 and 23 August 23 August
Harvesting date	21 November	November
Total rainfall (mm): June-November	157.2	178.8

The crop emergence across all the varieties was uneven at Merredin. At the first timing of post-emergent spraying (Z12-Z13), 90% of the plants were at 2-3 leaf stage and the remaining 10% were at 1-1.5 leaf stage. At the crop anthesis stage at both sites, a hand held GreenSeeker® unit was used to record the effect of herbicide treatments on crop biomass. GreenSeeker® is an integrated optical sensing system that measures crop health and vigour in terms of normalised difference vegetative index (NDVI).

As label rates of Dual®/Metolachlor 720® and dicamba (either alone in mixture with other herbicides) provide poor weed control, higher than label rates of these products were evaluated to determine if label rates could be revised for more effective weed control in wheat.

RESULTS AND DISCUSSION

The effect of herbicides during early crop growth, at flowering and on seed yield (Table 1) of wheat varieties is as follows:

- Two weeks after spraying, Affinity® + MCPA caused severe spotting on the leaves exposed to spray across all the varieties at Katanning. On an average 40% of the leaves appeared burnt/necrotic. In some cases even the growing point was affected. As the treatment was

sprayed early in the morning at 8.45 a.m., presence of dew on leaves or high leaf moisture content or high relative humidity might have contributed to the observed severe symptoms. These effects were mitigated by the time crop reached the anthesis stage, as there was no effect on crop biomass and no significant negative effect on grain yield. In contrast to this observation at Katanning, no visual symptoms were observed with this mixture at Merredin, but it resulted in significant yield reduction in Kalka, WAWHT 2773 and Wyalkatchem.

- Diuron 500 + MCPA amine also caused moderate to severe spotting on the leaves exposed to spray across all the varieties at Katanning. Although these symptoms were no longer apparent at flowering stage and no effect on crop biomass was detected (NDVI), but this treatment resulted in significant yield reduction across all the varieties. At Merredin, this treatment caused no visual leaf symptoms, and had no negative effect on biomass and grain yield of the varieties.
- Higher than the registered rate of metolachlor 720/Dual® (2 L/ha) caused a significant yield reduction in Jitarning at Katanning. When tank mixed with Diuron 500 (1 L/ha), it was safe to all the varieties including Jitarning. This indicates that mixing of diuron with Dual® increases both crop safety and the spectrum of weeds controlled. These treatments had no negative effect on any of the varieties at Merredin. The maximum rate of Dual® registered in wheat is 0.5 L/ha and can be mixed with 1 L of Diuron 500/ha. Use of diuron in mixture with Dual® Gold is not registered.
- Ally® caused 10-20% stunting/biomass reduction across all the varieties, two weeks after spraying at Katanning. This effect was still evident in EGA 2248 and Wyalkatchem until flowering stage, but did not result in a significant reduction in yield. In contrast, Ally caused no visual symptoms at Merredin, but resulted in significant yield reduction across all the varieties except Wyalkatchem (marginally insignificant). Ally® caused a significant yield reduction in Kalka which is in contrary to the previous results.
- Jaguar®, Tigrex® and Paragon® resulted in 10-25% spotting or bleaching of the leaves exposed to spray. The intensity of symptoms was more evident at Katanning than Merredin, and higher with Paragon® than other herbicides. Paragon® caused a significant yield reduction in WAWHT 2740, WAWHT 2273 and Wyalkatchem. In these trials higher rate of Paragon® (0.5 L/ha) was used on the younger crop (Z13) than the registered timing of 5 leaf stage onwards. At the time of its spray at Merredin, most of the plants had 3-5 leaves, and no significant negative effect on any of the varieties was recorded. Jaguar® reduced Kalka's yield significantly and it does not agree with the previous results.
- Hoegrass® + Achieve® caused a significant yield reduction in all the varieties except Binnu at Merredin and this reduction in WAWHT 2773 and Wyalkatchem is in contrary with the previous results. Similarly 2,4-D ester and dicamba significantly reduced grain yield of Jitarning and WAWHT 2773, respectively. This result is congruent with previous results for 2,4-D, but has not been observed previously with dicamba.
- Potential new herbicides Boxer Gold (tested as A14429B) and Cheetah Gold (group A) were tolerated well by all the new varieties except WAWHT 2773 which showed lower crop safety margins to Boxer Gold at Merredin.
- These trial results show that visual herbicide phytotoxicity symptoms are not always indicative of yield loss.

KEY WORDS

wheat, herbicide, tolerance

ACKNOWLEDGMENTS

We gratefully acknowledge GRDC for funding this project. Thanks to Leanne Young (Merredin), Vince Lambert (Katanning), Chris Roberts (Northam) and Dave Nicholson (Geraldton) for their excellent technical assistance. Thanks to Mario D'Antuono for his help in statistical analysis.

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Paper reviewed by: John Moore and Steve Penny

Table 1. Effect of herbicides on grain yield (% of untreated control) of wheat varieties (WA = WAWHT, Wyalkat = Wyalkatchem, Sapphire = GBA Sapphire)

No.	Herbicides (rate/ha)	Timing	Merredin (ME)					Katanning (GS)						
	06NO29		Binnu	Kalka	WA2740	WA2773	Wyalkat	Binnu	Bullaring	EGA2248	Jitarning	Sapphire	WA2773	Wyalkat
1	Untreated control >>>> kg/ha		1257	1328	1365	1240	1377	1273	844	1455	995	1113	1334	1283
2	Glean® 20 g	Before	112	97	93	87	97	102	97	112	109	109	88	98
3	Logran® B Power 50 g + Hasten® 0.5%	seeding	115	114	110	101	95	102	95	113	111	94	109	97
4	Stomp® 330 1.8 L	"	111	93	92	92	104	104	105	88	101	94	98	88
5	Triflur® X 2 L	"	94	115	100	106	99	91	99	109	93	95	100	104
6	Metolachlor 720 (Dual®) 2 L	"	99	95	94	90	104	90	126	88	74	95	100	96
7	Diuron 500 1 L + Metolachlor 720 2 L	"	101	143	100	116	102	106	106	101	112	113	103	109
8	Boxer* Gold 2.5 L	"	90	89	94	87	100	114	108	121	110	96	104	114
9	Boxer* Gold 5.0 L	"	101	110	99	79	88	102	111	99	102	105	97	107
10	Axial® 300 mL + Adigor® 0.5%	Z12-Z13	98	85	92	90	92	104	112	103	85	99	100	97
11	Achieve® WG 380 g	(ME)	122	102	111	98	98	106	107	117	108	105	112	98
12	Jaguar® 1 L	Z13-Z15	100	81	88	101	89	93	110	107	121	108	105	86
13	Monza® 25 g + DC Trate 2%	(GS)	112	101	92	92	106	104	101	115	108	104	101	94
14	Hoegrass® 375 2 L + BS 1000 0.25%	"	99	106	88	90	80	102	109	118	118	105	112	117
15	Cheetah** Gold 1 L + Hasten® 1%	"	95	95	93	91	96	90	93	96	110	87	91	93
16	Hoegrass® 200 mL+ Achieve® 200 g	"	87	79	77	70	70	117	104	118	100	103	102	102
17	Ally® 5 g + BS 1000 0.25%	Z13-Z14	82	74	84	83	84	100	90	103	97	97	89	87
18	Atlantis® 330 mL + Hasten® 1%	(ME)	100	110	99	105	95	109	100	111	106	105	103	103
19	Broadside® 1 L	Z13-Z15	104	111	90	104	121	102	103	104	114	100	98	114
20	Hussar® 200 g + BS 1000 0.25%	(GS)	93	101	105	102	94	100	115	116	99	112	94	107
21	Mataven® L 3 L	"	81	84	89	89	90	118	110	104	119	97	109	127
22	Paragon® 0.5 L	"	90	93	81	79	73	97	113	110	118	115	99	107
23	Tigrex® 1 L	"	102	113	90	109	108	103	99	97	93	100	95	108
24	Buctril® MA 1.4 L	"	104	101	82	100	96	101	117	112	115	95	99	104
25	Affinity® 50 g + MCPA 0.5 L	"	91	76	88	83	78	109	84	92	88	97	90	96
26	Eclipse® 5 g + MCPA LVE 0.5 L	"	94	99	96	87	89	112	109	113	114	100	93	118
27	Diuron® 0.5 L + MCPA (amine) 0.5 L	"	98	98	96	92	87	82	74	71	72	78	75	76
28	MCPA amine 500 2 L	Z15-Z16	104	111	109	93	109	91	91	88	104	89	104	89
29	2 4-D amine 625 1.3 L	(ME)	98	98	104	110	107	98	92	87	91	102	96	101
30	2 4-D ester 800 0.7 L	Z16-Z17	107	97	96	106	101	101	86	93	69	100	93	87
31	Dicamba 500 0.5 L	(GS)	99	106	89	90	93	102	99	91	102	93	82	98
Isd (0.05) herbicides v/s Untreated			17	17	15	17	17	15	22	16	17	16	14	17

Treatments 10 and 15 + Supercharge® 0.75%; 25 + Uptake® oil 0.5%, figures in **bold** are significantly different from untreated control, * Registration expected in 2008 and ** in March 2007.

Herbicide tolerance of new barley varieties

Harmohinder Dhammu¹, Research Officer, **Vince Lambert²** and **Chris Roberts¹**,
Technical Officers, Department of Agriculture and Food, Western Australia,
¹Northam and ²Katanning

KEY MESSAGES

- Potential new variety WABAR2321 showed tolerance to all the herbicides tested.
- WABAR2288 and WABAR2310 showed sensitivity to dicamba applied at near twice the registered rate, and WABAR2288 to the highest registered rate of 2,4-D amine.
- Vlamingh showed sensitivity to Ally® and Axial®, and Hamelin yield was reduced significantly by Hoegrass®, Buctril® MA, diuron + MCPA and 2,4-D ester.
- Potential new herbicides Boxer Gold and Cheetah Gold were tolerated well by all the varieties.

AIM

To evaluate the herbicide tolerance of potential and recently released barley varieties.

METHOD

Five barley varieties (Hamelin, Vlamingh, WABAR2288, WABAR2310 and WABAR2321) were sown (randomised) on 4 July 2006 at Katanning Research Station, on a duplex sandy loam soil (pH (CaCl₂) 5.2) in three blocks (reps) of 10 m wide parallel strips. Strips were sown at 75 kg/ha with Superseeder points (573 Combine). Agstar Extra Plus was applied at 100 kg/ha with the seed. A range of herbicide treatments (Table 1) were applied randomly in three meter wide strips across the variety strips either, before crop seeding (3 and 4 July) or 3-5 leaf stage (16 August) or 5-7 leaf stage (23 August). Every 8th plot was kept as an untreated control to assess spatial variability. At the time of application of pre-emergent herbicide treatments soil moisture content at 0-10 and 10-20 cm depth was 12.5 and 6.4%, respectively. The soil moisture content was determined by the Gravimetric method. In early September, manganese deficiency was observed across all the varieties, so Mantrac was applied at 0.5 L/ha on 12 September. To control low density of wild radish, a blanket spray of Bromicide® 200 (2 L/ha) was applied on 14 September. The trial was harvested in November 2006. Total rainfall from June to November at Katanning was 179 mm.

As label rates of Dual®/Metolachlor 720® and dicamba (either alone in mixture with other herbicides) provide poor weed control, higher than label rates of these products were evaluated to determine if label rates could be revised for more effective weed control in barley.

RESULTS AND DISCUSSION

The effect of herbicides during early crop growth, at flowering and on grain yield (Table 1) of barley varieties was as follows:

- Two weeks after spraying, Affinity® + MCPA caused severe spotting on the leaves exposed to spray across all the varieties. On average 35-55% of the leaves appeared burnt/necrotic. WABAR2321 was most affected and WABAR 2288 was least affected. As the treatment was sprayed early in the morning at 8.40 a.m., presence of dew on leaves or high leaf moisture content or high relative humidity might have contributed to the observed severe symptoms. The treatment effect in terms of reduced biomass (10%) across all the varieties was visible up till anthesis stage, but this didn't result in a significant yield reduction in any of the varieties.
- Diuron + MCPA also caused moderate (20%) spotting on the leaves exposed to spray across all the varieties. The treatment effect in terms of reduced biomass (on an average 10%) across all the varieties was visible up till the crop anthesis stage, but only Hamelin suffered a significant yield reduction.

- Ally® caused stunting/biomass reduction (20%) and slight yellowing during the early crop growth and the negative effect on crop biomass continued up to crop anthesis stage with reduced intensity (10%) across all the varieties. The significant yield reduction with this treatment was recorded in Vlamingh only.
- Jaguar®, Tigrex® and Paragon® caused slight spotting or bleaching on the leaves (10-15%) exposed to spray, but there was no effect on grain yield of any of the varieties tested. In this trial a higher rate of Paragon® (0.5 L/ha) was used at an earlier growth stage (Z13) than the registered time of application of 5 leaf stage onwards. Results indicate that 0.5 L/ha Paragon at Z13 seems safe on the barley varieties (this result should be treated as preliminary).
- Axial reduced the yield of Vlamingh, 2,4-D (amine) reduced the yield of WABAR2288 and dicamba reduced the yield of WABAR2288 and WABAR2310. The grain yield of Hamelin, a standard barley variety in the trial, was not affected by these treatments. Further testing of these varieties is needed to determine whether results are consistent or not.
- The significant yield reduction in Hamelin by Hoegrass®, diuron + MCPA, Buctril® MA and 2,4-D (ester) is in contrary to the previous results and interestingly no other barley variety in this trial was significantly affected by these herbicides.
- Potential new herbicides Boxer Gold (tested as A14429B) and Cheetah Gold (group A) were tolerated well by all the varieties. Cheetah Gold and Boxer Gold are expected to be registered in barley by March 2007 and early 2008, respectively.

KEY WORDS

barley, herbicide, tolerance

ACKNOWLEDGMENTS

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Paper reviewed by: John Peirce and Steve Penny

Table 1. Effect of herbicides on grain yield (% of untreated control) of barley varieties at Katanning (06NO21)

No.	Herbicides (rate/ha)	Timing	Hamelin	Vlamingh	WABAR 2288	WABAR2310	WABAR 2321
1	Untreated Control >>>>> kg/ha		1100	1128	1455	1328	1244
2	Stomp® 330 1.8 L	Before	113	114	118	104	107
3	Triflur® X 2 L	seeding	115	122	101	105	107
4	Triflur® X 1 L + Lexone® 150 g	"	109	102	103	107	94
5	Metolachlor 720 (Dual®) 2 L	"	110	118	94	112	103
6	Diuron 1 L + Metolachlor 720 (Dual®) 2 L	"	94	130	91	92	101
7	Boxer* Gold 2.5 L	"	90	102	98	103	106
8	Boxer* Gold 5 L	"	110	109	115	129	123
9	Glean® 20 g + BS 1000 0.1%	Z13-Z15	105	107	113	112	107
10	Jaguar® 1 L	"	98	93	104	88	110
11	Cheetah** Gold 1 L + Hasten® 1%	"	113	85	94	100	103
12	Axial® 300 mL + Adigor® 0.5%	"	103	80	100	103	97
13	Hoegrass® 375 1.5 L + BS 1000 0.25%	"	82	99	89	98	104
14	Hoegrass® 200 mL+ Achieve® 200 g	"	103	114	106	104	96
15	Achieve® 380 g + Supercharge® 0.75%	"	111	104	111	106	97
16	Ally® 5 g + BS 1000 0.25%	"	89	80	101	86	92
17	Paragon® 0.5 L	"	99	102	112	109	103
18	Tigrex® 1 L	"	103	117	91	89	101
19	Buctril® MA 1.4 L	"	80	116	116	99	111
20	Affinity® 50 g+ MCPA (amine) 0.5 L	Z15-Z17	86	83	89	88	98
21	Eclipse® 5 g + MCPA LVE 0.5 L	"	104	93	98	110	106
22	Diuron 0.5 L + MCPA (amine) 0.5 L	"	78	86	99	86	101
23	MCPA amine (50%) 2 L	"	103	97	110	99	115
24	2 4-D amine 625 1.3 L	"	95	119	86	99	107
25	2 4-D ester (80%) 0.7 L	"	85	105	94	102	106
26	Dicamba (50%) 0.5 L	"	89	101	70	75	99
Isd (0.05) Herbicides v/s untreated			15	19	13	16	18
Isd (0.05) Herbicides v/s herbicides			20	25	17	21	24
CV%			15	18	13	16	17

Treatments 14 applied with Supercharge 0.75%, 21 with Uptake oil 0.5% v/v. Figures in **bold** are significantly different from untreated control.

* Registration is expected in 2008 and ** in March 2007.

Herbicide tolerance of new oat varieties

Harmohinder Dhammu¹, Research Officer, **Vince Lambert²** and **Chris Roberts¹**, Technical Officers, Department of Agriculture and Food, Western Australia, ¹Northam and ²Katanning

KEY MESSAGES

- The oat varieties showed good tolerance to all the pre-emergent herbicides tested.
- All the varieties showed sensitivity to 2,4-D ester and dicamba, Kojonup and Possum also to 2,4-D amine and Wandering to MCPA amine.
- Jaguar® and diuron + MCPA reduced grain yield both of Possum and Wandering, Eclipse® + MCPA and Igran® + MCPA of Possum, and Affinity + MCPA amine of Wandering only.
- Eclipse® 5 g/ha applied at anthesis stage (Z69) showed crop safety similar to Logran® 10 g/ha.

AIM

To evaluate the herbicide tolerance of recently released oat varieties.

METHOD

Four oat varieties (Kojonup, Mitika, Possum and Wandering) were sown (randomised) on 4 July 2006 at Katanning Research Station (GSARI), on a gravelly sandy loam soil (pH (CaCl₂) 5.2) in three blocks (reps) of 10 m wide parallel strips. Strips were sown at 75 kg/ha with Superseeder points (573 Combine). 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 the variety strips either before crop seeding (3 and 4 July) or at 3-4 leaf stage (16 August) or 4-6 leaf stage (23 August) or at the flowering stage (10 October). Every 8th plot was kept as untreated control to assess the spatial variability. At the time of pre-emergent herbicide treatments application, soil moisture content at 0-10 and 10-20 cm depth was 12.0 and 6.4%, respectively. The soil moisture content was determined by following the gravimetric method. To determine the effect of pre-emergent herbicide treatments (selected only) on plant density, the oat plants were counted from two randomly selected 25 cm x 25 cm quadrats per plot, seven weeks after seeding the crop. In early September, manganese deficiency was observed across all the varieties, so Mantrac at 0.5 L/ha was applied on 12 September. To control a low density of wild radish, a blanket spray of Bromicide® 200 (2 L/ha) was applied on 14 September. The trial was harvested in November 2006. Total rainfall from June to November at Katanning was 179 mm.

As label rates of Dual®/Metolachlor 720® and dicamba (either alone in mixture with other herbicides) provide poor weed control, higher than label rates of these products were evaluated to determine if label rates could be revised for more effective weed control in oats.

RESULTS AND DISCUSSION

The effect of herbicides during early crop growth, at flowering and on grain yield (Table 1) of oat varieties was as follows:

- All the oat varieties tolerated double the rate registered in wheat and barley of Triflur® X and Stomp®, eight times the rate of Dual®, four times the Dual rate in mixture with double the registered rate of diuron (in oats) and proposed rate of Boxer Gold (2.5 L/ha) without any visual symptoms and significant negative effect on grain yield of the oat varieties. The higher rate of Boxer Gold (5 L/ha) caused no significant reduction in plant density, but resulted in around a 10% biomass reduction/stunting during early crop growth stages and it remained evident up till crop anthesis stage. This treatment also had no significant negative effect on grain yield of the varieties. Currently Trifluralin (Triflur® X) and pendimethalin (Stomp®) are not registered in oats. As the 2006 season was drier than a 'normal year', and under such conditions sometimes soil applied/active herbicides don't express full activity, so further testing of these herbicides is needed to determine whether the results are reliable.

- Two weeks after spraying, Affinity® + MCPA caused severe spotting on the leaves exposed to spray across all the varieties. On an average 45-55% of the leaves appeared burnt/necrotic. Mikita was the most affected variety. As the treatment was sprayed early in the morning at 8.30 a.m., the presence of dew on leaves or high leaf moisture content or high relative humidity might have contributed to the observed severe symptoms. The treatment effect in terms of reduced biomass (10%) across all the varieties was visible up till crop anthesis stage, but only Wandering suffered a significant yield reduction.
- Diuron 500 + MCPA (amine) also caused moderate (25%) spotting on the leaves exposed to spray across all the varieties. Although the symptoms were no longer apparent at flowering stage, and no effect on crop biomass was observed, this treatment did result in a significant yield reduction in Possum and Wandering.
- Jaguar®, Tigrex® and Paragon® caused slight spotting or bleaching on the leaves exposed to spray across all the varieties. Jaguar reduced grain yield of Possum and Wandering significantly. The negative effect of Jaguar on Wandering was also observed in the previous trial conducted at Newdegate during 2000.
- Eclipse® + MCPA amine and Igran® + MCPA amine reduced grain yield of Possum significantly. Wandering – a standard oat variety was not affected negatively by these herbicides.
- 2,4-D ester and dicamba caused significant yield reduction across all the varieties, whereas 2,4-D amine reduced yield of Kojonup and Possum and MCPA amine reduced yield of Wandering only. The negative effect of phenoxy herbicides could be due to the shorter growing season last year.
- Eclipse® 5 g/ha applied at Z69 (anthesis completed) was as safe as Logran® 10 g/ha to all the oat varieties. Currently Logran is registered in oats for late wild radish control or seed set control, but Eclipse® is not registered for such a late application in oats. The trial results indicate that Eclipse® could be another option for oats. However, it needs further testing to confirm the results.

KEY WORDS

oats, herbicide, tolerance

ACKNOWLEDGMENTS

We gratefully acknowledge GRDC for funding this project. Thanks to John Moore, Sr Research Officer, Albany for his suggestions in the treatment planning in the trial and Dave Nicholson (Geraldton) for his technical assistance.

Project No.: DAW0134

Paper reviewed by: John Moore

Table 1. Effect of herbicides on grain yield (% of untreated control) of oat varieties at Katanning

No.	Herbicides (rate/ha)	Timing	Kojonup	Mitika	Possum	Wandering
1	Untreated control >>>>>>>> kg/ha		430	795	879	900
2	Treflur® X 2 L	Before	115	142	126	100
3	Treflur® X 4 L	seeding	161	117	102	125
4	Stomp® 330 1.8 L	"	135	109	104	108
5	Stomp® 330 3.6 L	"	146	114	91	111
6	Metolachlor 720 (Dual®) 2 L	"	120	114	101	91
7	Metolachlor 720 (Dual®) 4 L	"	149	108	88	93
8	Diuron 500 2 L	"	111	108	95	100
9	Diuron 500 2 L + Metolachlor 720 2 L	"	121	114	108	114
10	Boxer* Gold 2.5 L	"	139	134	96	104
11	Boxer* Gold 5.0 L	"	70	126	122	81
12	Glean® 20 g+ BS 1000 0.1%	Z13-Z14	152	117	126	105
13	Jaguar® 1 L	"	87	112	77	79
14	Tigrex® 1 L	"	115	102	120	105
15	Paragon® 0.5 L	"	156	87	89	106
16	Buctril® MA 1.4 L	Z14-Z16	79	106	87	92
17	Diuron 500 0.5 L + MCPA (amine) 0.5 L	"	145	93	78	77
18	Eclipse® 5 g + MCPA LVE (50%) 0.5L	"	88	107	71	87
19	Igran® (50%) 0.85 L + MCPA (amine) 0.6 L	"	133	107	77	96
20	Affinity® 50 g + MCPA amine (50%) 0.5 L	"	87	88	87	73
21	Broadstrike® 25 g + Uptake oil 0.5%	"	111	128	119	103
22	MCPA amine (50%) 2 L	"	137	111	84	77
23	2 4-D amine 625 1.3 L	"	51	78	68	85
24	2 4-D ester (80%) 0.7 L	"	33	53	37	49
25	Kamba® (dicamba) 0.5 L	"	31	47	24	57
26	Logran® 10 g + Uptake® oil 1%	Z69+	145	122	93	80
27	Eclipse® 5 g + Uptake® oil 1%	"	77	95	107	114
Isd (0.05) Herbicides v/s Untreated control			49	24	20	21
Isd (0.05) Herbicides v/s Herbicides			65	31	26	27
CV (%)			44	22	21	21

Treatment 18 applied with Uptake® oil 0.5%v/v. * Registration is expected in 2008.
 Figures in **bold** are significantly different from untreated control.

Research and extension needs for wild radish and other cruciferous weeds

Aik Cheam, Department of Agriculture and Food, Western Australia, South Perth

KEY MESSAGES

The key challenge to the management of wild radish and some of the cruciferous weeds is to be able to run down their persistent seedbanks rapidly and manage herbicide resistance effectively by putting the various control measures currently available together into workable systems at the farm level. Extension of all the available knowledge on wild radish should also be given high priority.

INTRODUCTION

A symposium on wild radish and other cruciferous weeds was held over a two-day period in July 2006 at the Department of Agriculture and Food, Western Australia (DAFWA). As part of this symposium, a session was conducted to identify research and extension priorities for this group of important weeds. These are presented below.

METHOD

At the start of the session on research and extension needs, participants were given a prepared list of research ideas generated at past meetings on wild radish and other related weeds. This process saved time because it avoided developing the same list of ideas that had been repeatedly raised at the various meetings. The list also included ideas extracted from the papers presented at the symposium. In addition, participants were given the opportunity to contribute new ideas after they had examined the prepared list.

The combined list was capped at 47 ideas and participants were then asked to rate each of the idea from one to 10, with 10 representing the highest research priority. Participants were asked to consider how achievable the various research and extension ideas were before ranking them in order of priority.

The votes for each research idea were then averaged so that a single score from one to 10 could be obtained for each research and extension idea.

RESULTS

Table 1 summarises the priorities and it is hoped that individuals will take up the challenge.

Table 1. Ranking of research and extension ideas for wild radish and other cruciferous weeds

Idea No.	Research and extension ideas	¹ Mean score	² Priority ranking	³ Project area
1	Prevention of seed set and enhancement of seedbank decline.	8.8	High	A
2	Focus farmers' attention on seedbanks.	8.1	High	G
3	Whole-farm approach to managing cruciferous weeds.	7.9	High	E
4	Extension package with control options available for growers.	7.9	High	G
5	Submission to CropLife to change herbicide classification system.	7.8	High	G
6	Market the idea of a 4-year plan for 100% seed set control.	7.3	High	G
7	Identifying herbicide options, mixtures, alternate mode or site of action for controlling resistant populations.	7.2	High	B
8	Crop-topping Farmnote for cruciferous weeds.	7.0	High	G
9	Quantifying the effectiveness of non-chemical control methods.	7.0	High	C
10	Identification publication for cruciferous weeds.	6.8	High	G
11	Developing new management strategies using current weed biology and ecology knowledge.	6.8	High	A
12	Better understanding of resistance mechanisms.	6.7	High	B
13	Infra-red/image recognition of flowering cruciferous weeds.	6.5	High	C

Table 1 continued ...

Idea No.	Research and extension ideas	¹ Mean score	² Priority ranking	³ Project area
14	Standardised resistance testing service that is quick, accurate and reliable.	6.5	High	B
15	Changing farming systems for weed and environmental management.	6.5	High	E
16	Selective growth regulators.	6.4	Medium	C
17	Canopy management vs crop competition (including timing of weed removal).	6.4	Medium	C
18	Determination of cross-resistance patterns in different populations of wild radish (as short-term options for various herbicide groups).	6.3	Medium	B
19	Weed seed spatial movement of herbicide resistant seeds and pollen/weed seed distribution and spread.	6.3	Medium	B
20	Development of self-incompatibility molecules to prevent seed production.	6.3	Medium	D
21	Introduce GM crops.	6.2	Medium	D
22	New methods of weed control by targeting genes and proteins encoded by these genes.	6.2	Medium	D
23	Early recognition of herbicide resistance in the field.	6.1	Medium	B
24	Prolonging the use of PSII inhibitors in view of the currently low frequencies of wild radish populations with resistance to these herbicides.	6.1	Medium	B
25	Increasing competitiveness of broadleaf crops against cruciferous weeds.	6.1	Medium	C
26	Increasing crop seeding rates to out compete weed populations with weak resistance (phenoxy and diflufenican resistance).	6.0	Medium	C
27	Predisposition of plants for increased herbicide uptake.	6.0	Medium	C
28	Potential for GM crops with other modes of action or herbicide groups.	6.0	Medium	D
29	Screening for safer herbicides to control seed set of wild radish and other weedy crucifers.	5.9	Medium	B
30	Germination stimulator (chemical).	5.7	Medium	C
31	Modelling the rate of development and spread of herbicide resistance.	5.6	Low	B
32	Development of techniques to reduce fitness or vigour of weeds.	5.5	Low	A
33	Screening for a wider range of herbicides to control wild radish in pulse crops. Include the selection of lines for increased herbicide tolerance.	5.4	Low	B
34	Nutrient stratification and weed control.	5.3	Low	C
35	Synergistic combinations of herbicides and pathogens.	5.2	Low	C
36	Developing a one pass post-emergent operation for shielded sprayer.	5.0	Low	C
37	Pod thickness and germination.	4.9	Low	A
38	Herbicide tolerant crop volunteers/GM → non-GM crops/gene flow/outcrossing.	4.9	Low	D
39	Alter pH of herbicide carrier.	4.6	Low	B
40	Developing a weed sterility gene.	4.3	Low	D
41	Options that increase predation.	4.3	Low	C
42	Identification of pathogens for biological control.	4.2	Low	C
43	Liquid fertilisers and adjuvants for desiccation +/- herbicides.	4.1	Low	C
44	Industrial oil from wild radish seed.	4.0	Low	F
45	DNA fingerprinting for monitoring hybridisation.	4.0	Low	D
46	1 m rows in lupins.	3.4	Low	C
47	Biotech to produce allelopathic compounds from wild radish.	3.3	Low	F

¹ Ranking scores ranged from 1-10; 10 = highest priority.

² Based on the ranking scores, the top 15 high ranking ideas were categorised as high priority, followed by the next 15 ideas as medium priority while the rest were considered of low priority.

Table 1 footnotes continued ...

³ Project area codes are as follows:

- A. Overcoming biological strengths/exploiting biological weaknesses of the weed.
- B. Herbicides and resistance management.
- C. Biological and other control measures.
- D. Molecular biology and GM crops.
- E. Integrated control.
- F. Alternative uses for weedy crucifers.
- G. Extension.

DISCUSSION ON PRIORITIES

Although time did not allow for detailed discussions of each idea or integration of research areas that overlapped, there was a good consensus on the research direction.

Preventing seed-set and enhancing seedbank decline attracted the highest research priority (ranked Priority 1) due to current concerns regarding herbicide resistance, seedbank longevity and high seed production of cruciferous weeds.

Surprisingly, screening for safer herbicides to control cruciferous weed seed-set and researching pod thickness and germination with the aim of enhancing seedbank decline were ranked poorly, receiving a 29 and 37 ranking, respectively. These poor rankings may have been because the symposium participants deemed the research already done in these areas to be adequate. However, further work is obviously needed to minimise weed seed-set and minimise the impact of herbicides on crops especially in pulses, poor competitors and for which there is a lack of effective chemical options for controlling cruciferous weeds.

The high ranking given to the need for seed-set/seedbank research was supported by the priority rankings given to focusing farmers' attention to seedbanks (Priority 2) and to the promoting the concept of a four-year plan for 100 per cent seed-set control (Priority 6). Although it is impractical to achieve complete seed-set control and total elimination of a weed seedbank in large-scale agro-ecosystems, it is still important to manage the weed seedbank at controllable levels. However, it is important to realise that in the case of wild radish if the initial seedbank is high, seedlings emerging even after four years of intensive seed-set control can still cause problems. Enhancing the depletion of the existing seedbank is therefore just as important as controlling seasonal seed set. More data on the rate of seedbank decline and on seed production at a range of densities and mixtures of competing species under different cropping conditions are urgently needed to produce reliable models for making long-term management decisions. It will be important to know how much seedbanks need to be reduced by before the management practices imposed are deemed successful.

Another highly ranked idea was the need to undertake a whole-farm approach to managing cruciferous weeds (Priority 3). This is best carried out in farmer-driven regional trials involving best bet versus standard local practice to demonstrate that IWM of the cruciferous weeds is possible. In this regard, it will be important to consider the feasibility of IWM and to identify any drawbacks associated with IWM practices. Adoption of the best agronomic practices with existing crops is necessary.

It was clear that extension will continue to be important based on the call by delegates for more extension activities in the form of publications on control options (Priority 4), crop-topping (Priority 8) and identification of cruciferous weeds (Priority 10). The book on the cruciferous weeds, an updated version of the CRC publication 'Managing Wild Radish,' is currently being written and will provide the latest information to growers and consultants.

Herbicide resistance research was ranked within the top 15 priorities. This high ranking is related to concerns that eventually we may lose most of our chemical options against wild radish due to the rapidly evolving resistance to one or more herbicide groups within many of the wild radish populations, especially in WA. The greatest challenge confronting WA farmers is to preserve the availability of the chemicals they have remaining for the control of wild radish in their crops and to find alternative measures for controlling populations that are already resistant. Related to this challenge is the need to change the Australian herbicide classification system by taking into consideration the sites and modes of action of herbicides so that it is brought into line with the current international system of the Herbicide Resistance Action Committee (Priority 5). By doing so, advice given to managing herbicide

resistance would become easier and more meaningful. Other ideas that fall within the herbicide resistance area include the need to identify herbicide options – both mixtures and herbicides with alternate mode or site of action for the control of the resistant populations (Priority 7). Herbicide mixtures remain a powerful tool for controlling resistant weed populations. Understanding resistance mechanisms and the need to standardise the resistance testing service so that it is quick, accurate and reliable was given a Priority 12 and 14, respectively. Because of the rapid development of herbicide resistance in wild radish in WA, it is not surprising that participants voted for quantifying the effectiveness of non-chemical control methods (Priority 9). However farmers generally prefer the chemical options unless they can be convinced that the alternative non-chemical options are effective enough.

Apart from the top 15 priorities, the remaining research ideas have been grouped under medium or low priority (Table 1). Some of the ideas were ranked poorly probably because they were viewed as long-term and risky in terms of their likely success and adoption (such as the call for the production of allelopathic compounds from wild radish). However, the 'blue sky' proposals, ideas 20 and 22 which call for the use of molecular biology to interfere with the processes of flowering and seed-set were considered of medium priority probably in recognition of their fresh approach.

Extension took top priority when ranking was based on the project areas (Table 2). This is not surprising given the considerable research effort to date, especially with wild radish, and most participants would have considered that it is simply a matter of putting all the available knowledge together for dissemination. Integrated control (E), and overcoming biological strengths/exploiting biological weaknesses (A) were ranked highly as well followed by herbicides and resistance management (B). After taking into consideration the biology and herbicide resistance issues, these areas are most likely to give the greatest return for research.

Table 2. Ranking of project areas

Project area	Mean score	Ranking
G. Extension	7.5	High
E. Integrated control	7.2	High
A. Overcoming biological strengths/exploiting biological weaknesses	6.5	High
B. Herbicide and resistance management	6.0	Medium
C. Biological and other control measures	5.8	Medium
D. Molecular biology and GM crops	5.3	Low
F. Alternative uses for weedy crucifers	3.7	Low

CONCLUSION

Concerns remain regarding the effective management of cruciferous weeds, especially wild radish in WA with its widespread herbicide resistance. These concerns highlight the need for effective measures to control resistant populations and to preserve herbicides that are still effective against wild radish. With the wide range of control measures available, the challenge will be to integrate the control options into workable systems at the farm level with the emphasis on running down the weed seedbank and managing herbicide resistance. Much work remains to be done and several areas for research have been identified which will provide the best options for improving the management of these weeds. At the same time, adequate dissemination of the knowledge about how to manage them is equally important and therefore education and extension have to be an integral part of any future control program.

KEY WORDS

wild radish, cruciferous weeds, research priority

ACKNOWLEDGMENTS

Thanks to the Cooperative Research Centre for Australian Weed Management, Department of Agriculture and Food, Western Australia, Western Australian Herbicide Resistance Initiative and the many participants for supporting this symposium.

Paper reviewed by: Janet Paterson

e-weed – an information resource on seasonal weed management issues

Vanessa Stewart¹ and Julie Roche², Department of Agriculture and Food, Western Australia, ¹Merredin and ²Northam

KEY MESSAGES

- New features to be incorporated in 2007 include a regular section on 'what weed is that?'
- e-weed is keen to receive contributions from industry that can provide information on how best to use different herbicide products.
- Will continue to provide the latest research results throughout the year.
- If you want to be added to the database to receive e-weed please e-mail your contact details to: e-weed@agric.wa.gov.au.

BACKGROUND

e-weed is an electronic newsletter providing information on weed related issues throughout the growing season. It is a somewhat irregular newsletter, providing information on issues as they arise. Since becoming available electronically the number of editions has varied from 8 to 18 editions in any given year of publication. The reason for this variation has been seasonal conditions and staff availability.

e-weed is compiled and edited by Vanessa Stewart. Contributions to each edition are largely from Department of Agriculture and Food researchers working on weed related projects. Regular contributions are also received from WAHRI and the CRC for Australian Weed Management. Contributions from anyone are both encouraged and very welcome, with editorial discretion.

CIRCULATION

e-weed is now sent directly to over 1200 recipients. This includes:

- ~ 630 growers
- ~ 180 research and development
- ~ 150 agribusiness (agronomists, resellers, etc.)
- ~ 90 chemical company (R&D, area managers, product development, etc.)
- ~ 50 farm consultants
- ~ 135 Eastern States based agronomists, researchers, etc.

The database and circulation/distribution of e-weed is managed by Julie Roche.

CONTENT/ISSUES COVERED

Regular features

Integrated weed management – With the increasing prevalence of herbicide resistance throughout Western Australia (and the rest of the world) there has been a need to have a strong emphasis on integrated weed management (IWM). The message of the importance of integrating weed management technology other than herbicides into weed management strategies is reinforced through the publishing of articles and data on individual weed management technologies throughout the season. A key role of e-weed is to collate data for individual tactics from as wide a range of sources as possible. While similar articles may be run each year they should have been amended and updated to incorporate the most recent research findings or farmer experiences.

Herbicide resistance – Frequent (unfortunately) articles on new resistance confirmations, resistance surveys, etc. are included in e-weed. This is not to spread the bad news further but a reminder to be vigilant and aware that herbicide resistance has developed in many different weed species and

herbicides. It is easy to focus on annual ryegrass and wild radish – our two worst resistant weeds but there is the need to ensure that strategies are in place to minimise the risk of developing resistance in other common weed species (e.g. wild oats, barley grass, brome grass, turnips, mustards, etc.).

Herbicide tolerance – Regular articles outlining the herbicide tolerance of different crop varieties designed to ensure maximum crop production through appropriate herbicide x variety choice.

Weed biology – Understanding weed biology can improve our ability to manage weeds. Feature articles on weed biology, seedbank life, fecundity, germination pattern are included in e-weed.

Seasonally specific weed management advice – Information on how seasonal conditions may impact on the biological parameters of crop production and weed competition/fecundity. Additional information on how certain climatic conditions may influence the effectiveness of different weed control strategies (especially herbicides).

Product registrations – Articles on new product releases or registrations are included to keep people up to date with what herbicide options are available. Changes to product registrations are also covered. Appropriate information on registered herbicide options can assist with QA compliance.

Legislative/policy/regulatory issues – Recently WA has seen the review of pesticide legislation, the introduction to parliament of the Biosecurity and Agricultural Management (BAM) Bill and the APVMA decision to suspend the use of 2,4-D HVE. e-weed provides updates on these events to keep the broader community informed of the implications of these decisions/policies.

Industry events – e-weed can be used as a forum to advertise events (seminars, field days, field walks, conferences, etc.) where there is a strong focus on weed related issues.

Herbicide efficacy – No point in money being spent on herbicides if the product is not applied effectively. Increasingly, we are including information on how to 'best' apply particular products under a range of circumstances. In 2007 this section will focus on getting herbicides to work better through increasing understanding of the factors that influence herbicide performance, including herbicide rate, adjuvants, water volumes, application technology, etc. In addition information on how to get the best out of 'older' products will be revisited.

SEASON 2007

This year it is planned to incorporate a number of new regular features these include:

'What weed is that?' – Photos or samples of unusual weeds are frequently sent to DAFWA for identification. This proposed segment of e-weed will feature these photos, with identification and information of the weed and where the knowledge exists information on how to control the weed.

'In review' – Every year there are hundreds of papers published in scientific journals from across the world that better help us understand weeds and weed management. Not everyone has access to these journals or the time to peruse and read the articles published in them. This segment of e-weed will provide brief reviews/summaries of key articles to help get the information out there.

'Favourite websites' – Increasingly the internet is becoming a key source of information. E-weed will feature and review 'favourite' or 'frequently' used web sites featuring of weed issues.

CONCLUSIONS

- If you want to receive e-weed please send your details to e-weed@agric.wa.gov.au or return the form available in your crop updates bag.
- Contributions and suggestions on issues to cover are very welcome please feel free to send them to e-weed@agric.wa.gov.au.

Paper reviewed by: Abul Hashem