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GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

DURUM

SECTION 6

WEEDS AND HERBICIDES

MORE INFORMATION

WeedSmart: www.weedsmart.org.au

GRDC 'Integrated Weed Management Manual': www.grdc.com.au/IWMM

Hart Field Trials: http://www.hartfieldsite.org.au/pages/trials-results/2014-trial-results.php

GRDC Ground Cover Supplement 'Herbicide Resistance': https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS104

WeedSmart App: https://grdc.com.au/apps

DPIRD 'Crop Weeds': https://www.agric.wa.gov.au/pests-weeds-diseases/weeds/crop-weeds

Weeds and herbicides

6.1 Overview

Durum wheat is typically less competitive with weeds than other crops, including bread wheat and barley.

Effective weed control is essential for durum wheat crops to make full use of stored summer rainfall, minimise grain yield losses and prevent weed seed contamination at harvest. Some tactics that can be used include:

- Variety and crop type choice (influencing herbicide options)
- Controlling weeds in preceding crops and fallow
- Rotating crops and herbicides
- Growing more competitive durum wheat crops
- Judicious use of herbicides at registered rates.

In many broadacre crops, there are varieties that vary in sensitivity to commonly used herbicides and tank mixes.

To review herbicide tolerance ratings for newer durum wheat varieties, go to http://www.nvtonline.com.au/wp-content/uploads/2016/04/SA-Wheat-Advanced-2015.pdf[1] (Note these ratings are based on South Australian information).

There are limited options available for safe and effective pre-emergent herbicide use in durum wheat nationally, including Western Australia, which further increases the importance of alternative weed control strategies.

Trials at South Australia's grower-led Hart agronomic field site in 2014 investigated crop competition aspects of seeding rate, seed bed utilisation, variety selection and row spacing for some of the newest durum wheat varieties compared to current bread wheat lines.

The trial aimed to identify the most effective of these techniques in terms of weed control, crop yield and grain quality. Key findings included:

- DBA-Aurora⍉ durum wheat and Mace⍉ bread wheat had similar ability to compete with weeds
- Use of higher seeding rates improved weed control
- Increased crop seeding rates resulted in less crop screenings.[2]

The trial plots were planted on May 28, 2014 and received fertiliser applications of diammonium phosphate (DAP, at a ratio of 18:20) plus 2 percent zinc (Zn) at a rate of 70 kilograms per hectare and Urea Ammonium Nitrate (UAN, at a ratio 42:0) at a rate of 95 Litres/ha on August 15.

Annual ryegrass (*Lolium rigidum*) was spread over the trial area at a rate of 10 kg/ha and gently 'tickled' in (using light cultivation) prior to seeding. Selected plots were also treated with a pre-emergent herbicide to create plots with varying weed pressure.

The pre-emergent herbicide used was IBS trifluralin (1.2 L/ha) + triallate (1.2 L/ha) applied on May 28, 2014.

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1 GRDC (2016) National Variety Trials: Wheat variety response to herbicides in South Australia, SARDI, GRDC and Government of South Australia Primary Industries and Resources, http://www.nvtonline.com.au/wp-content/uploads/2016/04/SA-Wheat-Advanced-2015.pdf

2 Goss, S and Wheeler, R (2014) Hart Field Trials: Weed competition — determining best management practices in durum wheat, SARDI Waite campus, http://www.hartfieldsite.org.au/media/2014%20Trial%20Results/2014_Results_Weed_competition_determining_best_management_preactices_in_durum_wheat.pdf

The trial found for DBA-Aurora⍉ durum wheat and Mace⍉ bread wheat, the use of a higher seeding rate gave the best annual ryegrass control in 2014, as highlighted in Table 1.

Table 1: The effect of seed rate and normal or spreader seeding boots on grain yield (t/ha) and grass seed set (heads/m^2) for DBA-Aurora⍉ durum wheat and Mace⍉ wheat at Hart, 2014. (Yield loss percentage is the difference between plots with high weed pressure compared to no weed pressure).[3]

Variety	Seeding boot	Seeding rate (seeds/m^2)	Ryegrass heads/m^2	Yield t/ha	Yield loss %
DBA Aurora⍉	Normal Boot	100	138	2.29	9.2
DBA Aurora⍉		200	90	2.44	12.2
DBA Aurora⍉		300	29	2.95	8.2
Mace⍉		100	100	3.02	9.6
Mace⍉		200	79	3.52	11.5
Mace⍉		300	52	3.75	3.9
DBA Aurora⍉	Spreader Boot	100	104	2.41	18.3
DBA Aurora⍉		200	67	2.75	10.8
DBA Aurora⍉		300	54	3.02	9.2
Mace⍉		100	138	3.19	8.3
Mace⍉		200	90	3.75	8.7
Mace⍉		300	29	3.83	7.4
LSD (P≤0.05)			**ns**	**0.27**	**2.6**

There was no benefit in weed control in the trials from using a spreader boot compared to a 'normal' boot typically used in SA. Trials in 2013 had found the use of a spreader boot reduced annual ryegrass numbers.

Using medium and low seeding rates progressively increased annual ryegrass head numbers.

The trials found DBA-Aurora⍉ and Mace⍉ were similar in ability to compete with annual ryegrass. This highlights the improved ability of DBA-Aurora⍉ to compete with weeds, compared to the durum wheat variety Tjilkuri⍉, which was less competitive with weeds than Mace⍉ in 2013 trials.[4]

The addition of pre-emergent herbicides provided very good annual ryegrass control (data not shown), which was also found in 2013 trials.

The addition of other management strategies was unable to improve the weed control further, according to the researchers.

Mace⍉ wheat had lower yield losses (on average 8.2 percent) compared to DBA-Aurora⍉ (on average 11.3 percent) when under high weed pressure in 2014.[5]

The lowest yielding treatments were those sown at a rate of 100 seeds per square metre.

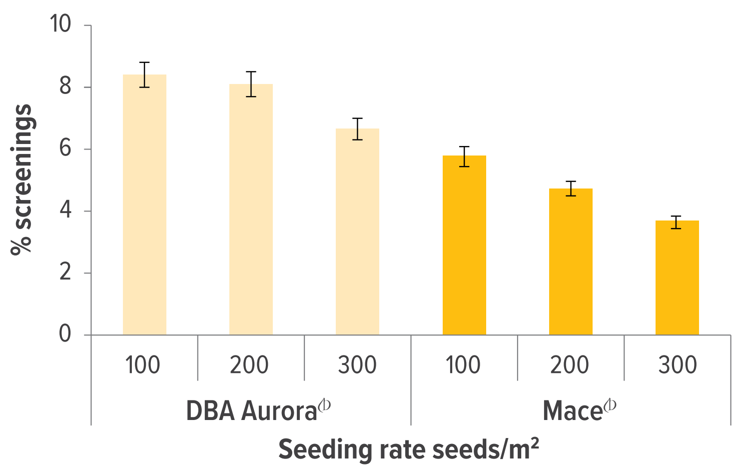
In Mace⍉ and DBA-Aurora⍉, increasing seeding rate reduced annual ryegrass head set and grain screening percentage, as shown in Figure 1.

3 Goss, S and Wheeler, R (2014) Hart Field Trials: Weed competition — determining best management practices in durum wheat, SARDI Waite campus, http://www.hartfieldsite.org.au/media/2014%20Trial%20Results/2014_Results_Weed_competition_determining_best_management_preactices_in_durum_wheat.pdf

4 Goss, S and Wheeler, R (2014) Hart Field Trials: Weed competition — determining best management practices in durum wheat, SARDI Waite campus, http://www.hartfieldsite.org.au/media/2014%20Trial%20Results/2014_Results_Weed_competition_determining_best_management_preactices_in_durum_wheat.pdf

5 Goss, S and Wheeler, R (2014) Hart Field Trials: Weed competition — determining best management practices in durum wheat, SARDI Waite campus, http://www.hartfieldsite.org.au/media/2014%20Trial%20Results/2014_Results_Weed_competition_determining_best_management_preactices_in_durum_wheat.pdf

Figure 1: *Effect of seeding rate and crop variety on screenings percentage (percent less than 2.00 mm) when grown in presence of annual ryegrass.*[6]



The results from the Hart Field Trials in 2013 and 2014 indicated increasing wheat seeding rates can lessen the impact of suppressed grain yields that can result from high weed pressure.

The trials also found having a high seeding rate not only restricts annual ryegrass growth, but can reduce the amount of grain screenings at harvest.

Results from 2014 show very similar levels of response to weed competition from Mace⁽ᴰ⁾ and DBA-Aurora⁽ᴰ⁾.[7]

6.2 Herbicide resistance

Herbicides act by targeting specific plant processes and this activity is termed mode-of-action (MOA).

In Australia, all herbicides are classified into groups based on their MOA and named with a group letter from A to Z.

MOA groups are ranked according to the risk of weed populations becoming resistant to those herbicides. Groups A and B are high risk and Groups C to Z are moderate risk. There are no low-risk herbicides.

Herbicide weed control in WA cropping systems is heavily reliant on six MOAs and multiple herbicide resistance is now the 'normal' status for the State's two most costly cropping weeds — annual ryegrass and wild radish (*Raphanus raphanistrum*).

Glyphosate resistant annual ryegrass, wild radish and brome grass (*Bromus rubens*) have also been found in winter cereal crops in WA.[8]

A 2013 pre-harvest and targeted statewide survey found more than 40 percent of 172 annual ryegrass samples tested had some level of resistance to glyphosate.[9]

The herbicide resistance status of major weeds found in WA is outlined in Table 2.

MORE INFORMATION

AHRI Ryegrass Surveys, 2010. http://ahri.uwa.edu.au/research/surveys/ryegrass-2/

GRDC 'Integrated Weed Management Manual': www.grdc.com.au/IWMM

6 Goss, S and Wheeler, R (2014) Hart Field Trials: Weed competition — determining best management practices in durum wheat, SARDI Waite campus, http://www.hartfieldsite.org.au/media/2014%20Trial%20Results/2014_Results_Weed_competition_determining_best_management_preactices_in_durum_wheat.pdf

7 Goss, S and Wheeler, R (2014) Hart Field Trials: Weed competition — determining best management practices in durum wheat, SARDI Waite campus, http://www.hartfieldsite.org.au/media/2014%20Trial%20Results/2014_Results_Weed_competition_determining_best_management_preactices_in_durum_wheat.pdf

8 GRDC (2012) Fact Sheet — Herbicide resistance, Western Region, GRDC, https://grdc.com.au/GRDC-FS-HerbicideResistance

9 Peltzer, S (2014) eWeed It's time — implement your glyphosate resistance management plan now, DAFWA, https://www.agric.wa.gov.au/newsletters/eweed-volume-152-april-2014

FEEDBACK

Table 2: Characteristics and herbicide status of major weeds of winter cereals in Western Australia.[10]

Weed and WA herbicide resistance status	Biological strengths and weaknesses
WILD RADISH	
Group B — sulfonylureas Group B — sulfonamides Group B — imidazolinones Group C — triazines Group C — triazinones Group F — nicotinanalides Group I — phenoxys Group M — glyphosate	Prolific seeder and highly competitive can cause yield losses of 10-90%. Wild radish has significant seedbank dormancy: one year of seed allowed to escape into the soil can mean more than seven years of subsequent weed germinations. Up to 70% of the seeds are still dormant at the start of the next cropping season: many seeds will not germinate until the second season after their formation (about 18 months later). Wild radish seeds become viable within three weeks from the appearance of first flowers: important to kill in-crop wild radish while small (less than 5 cm diameter). Most non-dormant seed germinates during autumn and winter but can emerge throughout the year provided there is sufficient soil moisture. Produces seed very quickly from germinations late in spring or during summer. Easily distributed (along with herbicide resistance) as an impurity in hay, chaff and grain. Retains seed at harvest height: late flushes and early survivors can be removed via the harvester.
ANNUAL RYEGRASS	
Group A — 'fops' Group A — 'dims' Group B — sulfonylureas Group B — imidazolinones Group C — triazines Group C — substituted ureas Group D — trifluralin Group M — glyphosate Group Q — triazoles *95% of resistant populations are resistant to both Group A and B herbicides.	Highly competitive – can compete as early as the two-leaf crop stage. Less competitive when emerging after crop: competitive crops can out-compete. Produces up to 45,000 seed/m^2 under ideal conditions: seed bank quickly replenished by uncontrolled survivors. 80% of seed germinates at break after two falls of rain exceeding 20 mm: good control possible with early start to season. Can emerge from late autumn-early spring depending on rainfall and seedbank levels: control early survivors and late flushes with harvest weed seed control. Germination drops with increasing seed depth seed, stopping at about 100 mm: strategic mouldboard ploughing can control bad infestations. Viable seed relatively short-lived in soil: can reduce seedbank by 75% per year with concerted control. Retains seed at harvest height: late flushes and early survivors can be removed during the harvesting operation.
WILD OATS	
Group A — 'fops' Group A — 'dims'	Highly competitive when left uncontrolled, can reduce wheat yields by up to 80%. Up to 20,000 seeds/m^2 produced in uncontrolled infestations. 40% germinates with opening rains with further 10-30% germinating during season. Viable seed short-lived in soil: can deplete seed bank by 75% per year with concerted control.
BROME GRASS	
Group B — sulfonylureas Group B — imidazolinones Group C — triazines	Highly competitive in wheat: keep seeding rate high and rows narrow to enable wheat to outcompete. More drought tolerant and responsive to nitrogen than wheat: N can aggravate brome grass problem. Can produce 600-3000 seeds per plant. Most seed shed before crop harvest: harvest weed seed control less effective than wild radish and ryegrass.

10 GRDC (2014) Integrated Weed Management Manual, Section 2 Herbicide resistance, GRDC, www.grdc.com.au/IWMM

No new herbicide MOAs are on the horizon and the most recent was commercialised in the early 1990s.

To help manage herbicide resistance, a range of techniques that intercept weed seeds at harvest before they re-enter the soil seedbank are being employed across vast areas of WA and in other parts of southern Australia — as well as being investigated for use in a range of grain growing countries globally.

Research shows it is possible to drive down the seedbank of some weeds by as much 95 percent in three to five years using an integrated approach involving crop competition, herbicide MOA rotation and harvest weed seed control (HWSC).[11]

But integrated weed management (IWM) requires a long-term and committed plan using herbicide, cultural and mechanical control measures, rather than just a year-to-year approach using herbicides alone.

The grains industry-led WeedSmart initiative, funded by GRDC, has a 10-point plan to deal with herbicide resistance and optimise weed control, as shown in Table 3.

11 GRDC (2014) Integrated Weed Management Manual, Section 2 Herbicide resistance, GRDC, www.grdc.com.au/IWMM

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Table 3: WeedSmart 10-point plan to prevent weed seeds from entering the soil seedbank.[12]

Tactic	Mechanism	Weed impact	More information
Develop a weed management plan	Understand the biology of your weeds. Be strategic and committed.	Knowledge of a weed's biology helps target its weaknesses.	Section 5 of the Integrated Weed Management Manual www.weedsmart.org.au/10-point-plan/act-now-to-stop-weed-seed-set/
Capture weeds at harvest	Consider your options – chaff cart, narrow windrow burning, baling, Harrington Seed Destructor. Compare the financial cost per hectare.	Research across southern Australia shows, on average, about 80% of annual ryegrass and wild radish seed entering the harvester can be collected via harvest weed seed control methods.	Section 4 of the Integrated Weed Management Manual www.weedsmart.org.au/10-point-plan/capture-weed-seeds-at-harvest/
Rotate crops and herbicide MOAs	Repeated application of effective herbicides with the same MOA is the single greatest risk factor for herbicide resistance evolution.	Crop rotation enables rotation of different herbicides and targeting of specific weeds. For example, sowing field peas enables delayed sowing, swathing and late herbicide application.	http://www.weedsmart.org.au/10-point-plan/rotate-crops-and-herbicide-modes-of-action/
Test for resistance	Measure resistance so you can manage it. Sample weed seeds before harvest for resistance testing.	Knowing your resistance status allows you to choose the most effective herbicides.	http://www.weedsmart.org.au/10-point-plan/test-for-resistance-to-establish-a-clear-picture-of-paddock-by-paddock-farm-status/
Never cut the rate	Always use the label rate. Using low herbicide rates can result in weeds with tolerance/resistance to multiple herbicides.	Herbicide resistance will develop faster in weeds exposed to low chemical rates. AHRI laboratory-based research demonstrated that ryegrass populations developed resistance to Sakura® after only three years of low application rates.	www.weedsmart.org.au/10-point-plan/never-cut-the-rate/ http://ahri.uwa.edu.au/creating-a-cross-resistant-monster/
Don't automatically reach for glyphosate	Diversity, diversity, diversity. Rotate to alternative knockdown herbicides. Consider strategic tillage.	Glyphosate resistance can be slowed by using alternative herbicides and introducing nonchemical weed control tactics.	www.weedsmart.org.au/10-point-plan/dont-automatically-reach-for-glyphosate/ www.glyphosateresistance.org.au/factsheets/Glyphosate_Resistant_weeds-beat_them_before_they_beat_you_DAFWA_Aug2014.pdf
Carefully manage spray events	Use best management practice to stop spray drift and maximise weed kill.	Monitor and destroy all weed escapes. Patch spray resistant weeds if required.	www.weedsmart.org.au/10-point-plan/carefully-manage-spray-events/ Refer to GRDC Fact Sheet series on best practice spray application: www.grdc.com.au/GRDC-FS-SprayPracticalTips
Plant clean seed into clean paddocks with clean borders	Plant weed-free crop seed. The density, diversity and fecundity of weeds is generally greatest along paddock borders and areas such as roadsides, channel banks and fencelines.	Recent AHRI* research showed nearly 75% of cleaned grain samples from 74 WA farms had some level of weed seed contamination. About 25% of the 347 Australian sites documented with glyphosate resistant annual ryegrass are from fence lines.	Section 4 of the Integrated Weed Management Manual http://www.weedsmart.org.au/10-point-plan/plant-clean-seed-into-clean-paddocks-with-clean-borders/ www.grdc.com.au/Resources/Factsheets/2010/11/Glyphosate-Resistance-fact-sheet
Use the double knock technique	Any combination of weed control that involves two sequential strategies (chemical and non-chemical). The second application/tactic is used to control survivors from the first.	The glyphosate/ paraquat double-knock uses different MOAs to eliminate weeds. Ensure the paraquat rate is high and start the double knock shortly after rainfall to tackle weeds while they are small.	Section 4 of the Integrated Weed Management Manual www.weedsmart.org.au/10-point-plan/use-the-double-knock-technique/
Use crop competitiveness to combat weeds	Increase your crop's competitiveness to win the war against weeds. Row spacing, seeding rate and crop orientation can help crops fight weeds and competitive cultivar eg barley.	Narrow rows out-compete weeds and deliver higher yields than wider rows. Sowing crops east-west instead of north-south can halve weed seed set.	Section 3 of the Integrated Weed Management Manual http://www.weedsmart.org.au/consider-narrow-row-spacing/

12 WeedSmart Website: www.weedsmart.org.au/10-point-plan/capture-weed-seeds-at-harvest/

The natural genetic variability of weed populations gives them an inherent capacity to adapt to herbicide and non-herbicide control measures.

If weed densities are kept low, the likelihood of resistance genes evolving within the population is also kept low and herbicide usefulness is extended, according to leading weeds researchers.

6.3 Herbicide resistance in WA

Wild radish, annual ryegrass, wild oats (*Avena fatua*) and brome grass are the most prolific and costly weeds affecting wheat production in WA and each has developed a level of herbicide resistance.

Multiple resistance to selective and non-selective herbicides is now standard for WA's two worst cropping weeds — annual ryegrass and wild radish.

It is estimated only 2 percent of annual ryegrass populations remain fully susceptible to herbicide control, with others resistant to one or more herbicide MOAs. More than 90 percent of wild radish populations are estimated to be resistant to one or more herbicides.[13]

A 2010 weed herbicide resistance survey found 84 percent of 96 wild radish populations tested from Geraldton in the north to Esperance in the south had some level of resistance to the Group B herbicide active chlorsulfuron.[14]

In recent years, WA has experienced a sharp increase in the level of herbicide resistance in wild radish to commonly used herbicides.

Key findings from the 2010 survey included:

- 84 percent of samples had plants resistant to chlorsulfuron (Group B)
- This was a 30 percent increase from 2003 levels
- 49 percent showed resistance to Intervix (Group B)
- 76 percent were resistant to 2,4-D amine (Group I), especially in the northern and central grainbelt
- 49 percent had resistance to Brodal® (Group F)
- One population had atrazine-resistant plants.[15]

Paddocks at high risk of developing herbicide resistance include those where there has been a long history of herbicide use and no management to prevent herbicide survivors from setting seed. These paddocks often have high weed numbers.

The goal is to ensure herbicide resistant weed seed does not enter the seedbank.

The expected time it will take for weeds to develop resistance to applications of the major herbicide groups is outlined in Table 4. The 'years of application' do not need to be consecutive applications.

13 Australian Herbicide Resistance Initiative, UWA (2010) Wild radish surveys, http://ahri.uwa.edu.au/research/surveys/wild-radish/

14 Australian Herbicide Resistance Initiative, UWA (2010) Wild radish surveys, http://ahri.uwa.edu.au/research/surveys/wild-radish/

15 GRDC (2014) Hot Topic — Wild radish control options in WA, GRDC, https://grdc.com.au/Media-Centre/Hot-Topics/Wild-radish-control-options-in-WA

Table 4: Predicted time (years) for weeds to develop resistance to each of the major herbicide groups.[16]

Herbicide group	Years of application
B	4
A 'fop'	6
A 'dim'	8
C	10-15
D	10-15
E	>15
F	10
G	>15
H	10
I	>20
K	>15
L	>15
M	>12

6.3.1 Rotation planning and weed control benefits

Continuous wheat rotations lack diversity in options for weed control using herbicides.

Including break crops in sequence planning opens up weed control options that are unavailable, or not suitable, to use in the wheat phase and can broaden the range of pre-emergent herbicide MOAs that can be used.

Rotating herbicide group MOAs helps to delay the onset of herbicide resistance.

Mixing two or more herbicides is also a sound strategy to prevent and delay the evolution of herbicide resistance.

Growing oaten hay or break crops to control annual ryegrass seedset and including competitive crops, such as barley, are important tools.

Growing field peas, lupins or pasture in the rotation allows for the use of late herbicide applications (for crop or pasture-topping) for weed seedset control.

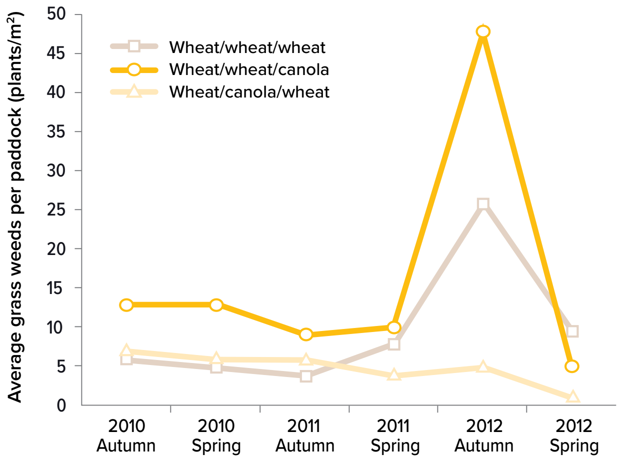
Problem weeds, such as herbicide resistant wild radish and annual ryegrass, can also be targeted with the inclusion of break crops in the cropping rotation — as weeds resistant to one herbicide MOA can be controlled using herbicides with a different MOA.[17]

For example, timely use of canola in the rotation has the ability to reduce the number of grass weeds for following crops using Group C herbicides and imidazolinone-tolerant and Roundup Ready® technologies – in combination with non-herbicide weed control methods, as shown in Figure 2.

16 GRDC (2014) Integrated Weed Management Manual, Section 2 Herbicide resistance, GRDC, www.grdc.com.au/IWMM

17 Harries, M and Anderson, G (2015) Crop and pasture sequences sustain wheat productivity, GRDC 2015 Update Paper, DAFWA, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Crop-and-pasture-sequences-sustain-wheat-productivity

Figure 2: *Impact of crop rotation on grass weed numbers in paddocks in a range of crop sequences.*[18]



Note: Canola following two years of wheat enabled grass weed numbers to be reduced from a high of 47 plants/m² in autumn to fewer than five plants/m² by spring

6.4 Post-emergent herbicides for wheat crops

Selective post-emergent herbicides often provide more than 98 percent control of common weeds found in WA cropping systems when applied under recommended conditions.[19]

Early removal of grass weeds, such as annual ryegrass and wild oats, reduces competition for resources in the crop.

Nozzle selection, droplet size, sprayer speed and meteorological conditions require careful attention to maximise spray efficacy.

Selective post-emergent herbicides for use in WA wheat crops belong to the herbicide MOA Groups:

» A (diclofop)
» B (metsulfuron)
» C (diuron)
» F (diflufenican)
» G (carfentrazone)
» H (pyrasulfotole)
» I (2,4-D, dicamba, picloram).

Post-emergent herbicides are often more reliable than pre-emergent herbicides, especially in low rainfall conditions, as pre-emergent herbicides rely on moist soil to achieve high levels of weed control.

Dry conditions following sowing often delay weed emergence.

Post-emergent herbicides can be applied after the bulk of weeds have emerged, at a time when the plants are most susceptible to the herbicide being applied.

This allows more flexibility in herbicide choice to control the particular suite of weeds in the crop — and identification of the most appropriate rate of application — compared to when using pre-emergent herbicides.

18 Harries, M and Anderson, G (2015) Crop and pasture sequences sustain wheat productivity, GRDC 2015 Update Paper, DAFWA, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Crop-and-pasture-sequences-sustain-wheat-productivity

19 GRDC (2014) Integrated Weed Management Manual: Section 4 Tactics for managing weed populations, GRDC, www.grdc.com.au/IWMM

Many post-emergent herbicides (such as bromoxynil and metsulfuron in wheat) have an extended application window due to a wide margin of crop safety.[20]

Depending on application rate, some post-emergent herbicides have a degree of pre-emergent or residual activity on susceptible weeds, which extends their period of weed control.

Residual activity is often related to application rate. Typically, the higher the rate, the longer the residual effect.

Soil moisture, organic matter, clay content, temperature, acidity (pH) and microbial activity can also influence the longevity (or availability) of post-emergent herbicides in the soil.

Hot and dry conditions increase the waxiness of weed leaves, which reduces herbicide absorption.

Plants suffering any kind of stress tend to have lower rates of translocation and the herbicide will take more time to reach sites of action.

Herbicide-tolerant crops can be damaged when stressed due to waterlogging, frost or dry conditions because they cannot produce sufficient levels of the enzymes that can break down the herbicide into harmless compounds.

6.4.1 Movement of post-emergent herbicides in plants

Knowing how a herbicide enters the plant and is translocated is important for determining the most appropriate application volume, adjuvant type and nozzle style. For example, some products (such as the contact herbicide paraquat) do not move/translocate well within plants and an even coverage of herbicide across the weed is required for effective control.

Other products (such as soil-applied herbicides and several fungicides), can only travel upwards in plants through the xylem and must be deposited onto the lower parts of plants to provide effective control above this point.

Some products (such as glyphosate and phenoxy herbicides) can move up and down the plant throughout the phloem and xylem, but only when the target plants are not stressed.

6.4.2 Post-emergent herbicides in integrated weed management plans

Early use of post-emergent herbicides can help maximise yield by removing weed competition when the crop is establishing.

Achieving good crop competition (with high seeding rates and narrow rows) and adopting harvest weed seed control (HWSC) measures, in combination with both pre and post-emergent herbicide use, can significantly reduce weed seed numbers over time.

Controlling herbicide resistant wild radish in WA wheat crops typically requires a two-spray, post-emergent herbicide approach — in combination with crop competition and HWSC.

20 GRDC (2014) Integrated Weed Management Manual: Section 4 Tactics for managing weed populations, GRDC, www.grdc.com.au/IWMM

MORE INFORMATION

GRDC Update Paper 'Why the Obsession with the Ryegrass Seedbank': www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Why-the-obsession-with-the-ryegrass-seed-bank

HerbiGuide 'Annual Ryegrass': http://www.herbiguide.com.au/Descriptions/hg_Annual_Ryegrass.htm

Ryegrass Integrated Management (RIM) model: www.ahri.uwa.edu.au/RIM

6.5 Annual ryegrass

Figure 3: *Annual ryegrass is a scourge of wheat crops in WA and across southern Australia.*

(SOURCE: GRDC)

Annual ryegrass can compete with a crop as early as the two-leaf crop stage.

This weed is active in winter and spring and can emerge from late autumn through to early spring. The number of emergence flushes and the density of plants are related to initial seedbank levels and the frequency and amount of rainfall.

Ideal conditions for germination of annual ryegrass include a significant autumn/winter rain event and seeds located at a soil depth of 20 mm. Germination levels reduce with increasing seed depth, stopping at about 100 mm.[21]

Most shallow seeds tend to germinate during autumn and early winter. Peak germination (80 percent of seeds) occurs at the break-of-season, typically after the first two falls of rain that exceed 20 mm.[22]

Newly-formed seeds of annual ryegrass tend to be dormant for about six months. Plants typically set seed in October and dormancy breaks in April-May in typical WA conditions.

About 20 percent of seed carries over for two seasons and about 5 percent carries over for three years, with seed life sometimes extending to four years.[23]

21 HerbiGuide 'Annual Ryegrass', http://www.herbiguide.com.au/Descriptions/hg_Annual_Ryegrass.htm

22 HerbiGuide 'Annual Ryegrass', http://www.herbiguide.com.au/Descriptions/hg_Annual_Ryegrass.htm

23 HerbiGuide 'Annual Ryegrass', http://www.herbiguide.com.au/Descriptions/hg_Annual_Ryegrass.htm

6.5.1 Annual ryegrass and herbicide resistance

Annual ryegrass produces very high numbers of seeds per plant.

Dense stands can produce up to 1000 kg/ha of seed.[24]

Annual ryegrass also is a host for the bacterium *Clavibacter* spp. that causes annual ryegrass toxicity (ARGT) affecting livestock.

Many populations of annual ryegrass have developed resistance to both selective and nonselective herbicides. Repeated use of herbicides from the same MOAs (particularly high-risk Groups A and B) have led to herbicide-resistant individuals.

Annual ryegrass has developed resistance to the following MOA herbicide groups in WA:

- Group A — 'Fops' (for example, diclofop-methyl)
- Group A — 'Dims' (for example, sethoxydim)
- Group B — sulfonylureas (for example, chlorsulfuron and sulfometuron)
- Group B — imidazolinones (for example imazapic)
- Group C — triazines (atrazine and simazine)
- Group C — substituted ureas (for example, diuron)
- Group D — trifluralin
- Group Q — triazoles (for example, amitrole)
- Group M — glyphosate
- Group L — paraquat.

It is estimated there would be several thousand unconfirmed populations of glyphosate-resistant annual ryegrass — along with many more glyphosate resistant cases in awnless barnyard grass (*Echinochloa colona*) and fleabane (*Conyza* spp.) populations — in Australia.[25]

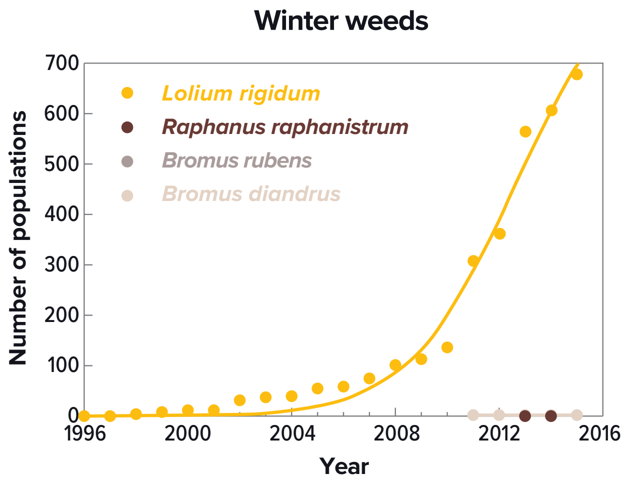
Testing has found more than 600 confirmed cases of glyphosate-resistant annual ryegrass populations in winter crops in WA, New South Wales, Victoria and SA. This is mostly from cropping paddocks and trends in incidence are shown in Figure 4.[26]

24 HerbiGuide 'Annual Ryegrass', http://www.herbiguide.com.au/Descriptions/hg_Annual_Ryegrass.htm

25 Preston, C (2016) Australian Glyphosate Sustainability Working Group — Australian glyphosate register — Glyphosate resistant weeds in Australia, University of Adelaide, http://www.glyphosateresistance.org.au/register_summary.html

26 Preston, C (2016) Australian Glyphosate Sustainability Working Group — Australian glyphosate register — Glyphosate resistant weeds in Australia, University of Adelaide, http://www.glyphosateresistance.org.au/register_summary.html

Figure 4: *The increase in confirmed cases of glyphosate resistance in winter weeds in Australia between 1996 and 2016.*[27]



All confirmed glyphosate-resistant weed populations in Australia have occurred in situations where there has been intensive use of glyphosate (often across 15 years or more), few or no other effective herbicide MOAs used and few other weed control practices put in place. This suggests the following factors are the main risks for glyphosate resistance evolution:

- Intensive use of glyphosate — every year or multiple times a year for 15 years or more
- Heavy reliance on glyphosate for weed control
- No other weed control used to stop seed set.

In 2013, there was a case of resistance to paraquat and glyphosate in a vineyard in WA's South West.

Flaxleaf fleabane (*Conyza bonariensis*) is the latest species confirmed to have resistance to paraquat in a vineyard in southern New South Wales. This fleabane population had been sprayed multiple times per year with top label rates of paraquat.

All cases of resistance to paraquat are in situations with long histories of use (more than 15 years).[28]

6.5.2 Control of annual ryegrass

There are many tactics that can be considered in an IWM plan to control annual ryegrass in WA cropping systems and in wheat crops in particular.

As outlined in Table 5, these include improved crop competition, burning residue, inversion ploughing, autumn tickle, using herbicides and HWSC tactics.

27 Preston, C (2016) Australian Glyphosate Sustainability Working Group — Australian glyphosate register — Glyphosate resistant weeds in Australia, University of Adelaide, http://www.glyphosateresistance.org.au/register_summary.html

28 Australian Herbicide Resistance Initiative (AHRI) (2013) Double banger — glyphosate and paraquat resistant ryegrass, http://ahri.uwa.edu.au/double-banger-glyphosate-and-paraquat-resistant-ryegrass/

FEEDBACK

Table 5: Tactics that should be considered when developing an integrated plan to manage annual ryegrass.[29]

Annual ryegrass (*Lolium rigidum*)		Most likely % control (range)	Comments on use
Agronomy	Improve crop competition	50 (20–80)	Optimum sowing rates essential. Row spacing >250 mm to reduce crop competitiveness. Sow on time.
Tactic	Burning residues	50 (0–90)	Avoid grazing crop residues. Use a hot fire back-burning with a light wind.
Tactic	Inversion ploughing	95 (80–99)	Bury seed greater than 100 mm deep. Use of skimmers on the plough is essential for deep burial.
Tactic	Autumn tickle	15 (0–50)	Only effective on last year's seedset. Use in conjunction with delayed sowing.
Tactic	Fallow and pre-sowing cultivation	60 (0–90)	Cultivation may lead to increased annual ryegrass in the crop. Use in combination with a knockdown herbicide. Use cultivators that bury seed.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	80 (30–95)	Avoid overuse of the one herbicide MOA group. Wait until annual ryegrass has more than 2 leaves.
Tactic	Double knockdown or 'double-knock'	95 (80–99)	Reduces the likelihood of glyphosate resistance. Use glyphosate followed by paraquat or paraquat + diquat 3 to 10 days later.
Tactic	Pre-emergent herbicides	70 (50–90)	Note incorporation requirements for different products and planting systems.
Tactic	Selective post-emergent herbicides	90 (80–95)	Apply as early as possible after the annual ryegrass has 2 leaves to reduce yield losses in cereals.
Tactic	Spray-topping with selective herbicides	80 (60–90)	Apply before milk dough stage of annual ryegrass.
Tactic	Crop-topping with non-selective herbicides	70 (50–90)	Note stage of crop compared to stage of annual ryegrass. Often not possible to achieve without crop yield loss. Most likely to occur with quick finish to season.
Tactic	Pasture spray-topping	80 (30–99)	Graze heavily in spring to synchronise flowering.
Tactic	Silage and hay – crops and pastures	80 (50–95)	Most commonly used where there is a mass of resistant annual ryegrass growth. Follow up with herbicides or heavy grazing to control regrowth.
Tactic	Manuring, mulching and hay freezing	90 (70–95)	Most commonly used where there is a mass of resistant annual ryegrass growth. Follow up with herbicides or heavy grazing to control regrowth.
Tactic	Grazing – actively managing weeds in pastures	50 (20–80)	Graze heavily in autumn to reduce annual ryegrass plant numbers. Graze heavily in spring to reduce seedset.
Tactic	Weed seed collection at harvest	65 (40-80)	Best results when crop is harvested as soon as possible before ryegrass lodges or shatters.
Tactic	Sow weed-free seed	85 (50-99)	Reduces the risk of introducing resistant annual ryegrass to the paddock with crop seed.

29 GRDC (2014) Integrated Weed Management Manual: Section 4 Tactics for managing weed populations, GRDC, www.grdc.com.au/IWMM

Newly-set seed of annual ryegrass is predominantly dormant. While most of this dormancy is lost over summer, some seed can remain dormant at the season break and limit the proportion of the seedbank that can emerge and be controlled.

Annual ryegrass emergence will be highest at the autumn break when:

» Seed has formed during a hot dry spring in the previous year
» Summer is very hot (faster dormancy release)
» There have been heavy rainfall events during a hot summer
» There is a late break to the growing season.

If these conditions occur simultaneously, there is a valuable opportunity to delay seeding in problem annual ryegrass paddocks to allow maximum weed germination and kill pre-sowing.

Increasing glyphosate resistance levels in annual ryegrass populations makes the double-knock (an application of glyphosate typically followed by an application of paraquat) a highly effective pre-sowing herbicide tactic.[30]

The most effective double-knock interval between the glyphosate and paraquat applications is between two and 10 days for seedling annual ryegrass plants.[31]

Maximum control of annual ryegrass results from an application of herbicide at the three to four-leaf stage. Annual ryegrass treated at the zero to one-leaf stage can potentially regrow from seed reserves.[32]

Herbicide treatments can be highly effective in reducing in-crop annual ryegrass populations within five consecutive growing seasons. But research trials in the northern region found it was only in the paddocks where both early season herbicides and HWSC were routinely practiced that very low weed densities were achieved.

Stubble cover of 50-90 percent has been shown to reduce the performance of pre-emergent herbicides, such as trifluralin, for annual ryegrass control. Increasing the carrier volume of these herbicides can significantly increase weed kill.[33]

Research and experience is indicating that burying annual ryegrass seed deep using a mouldboard plough operation every 10-20 years can reduce the weed seedbank by as much as 99 percent, enabling problem paddocks to be 're-set' in terms of annual ryegrass numbers.[34]

Combining herbicide control with HWSC measures has reduced annual ryegrass seed bank levels to near zero in some northern WA grainbelt paddocks, as outlined in Figure 5.

30 GRDC (2012) Fact Sheet — Herbicide resistance, Western Region, GRDC, https://grdc.com.au/GRDC-FS-HerbicideResistance

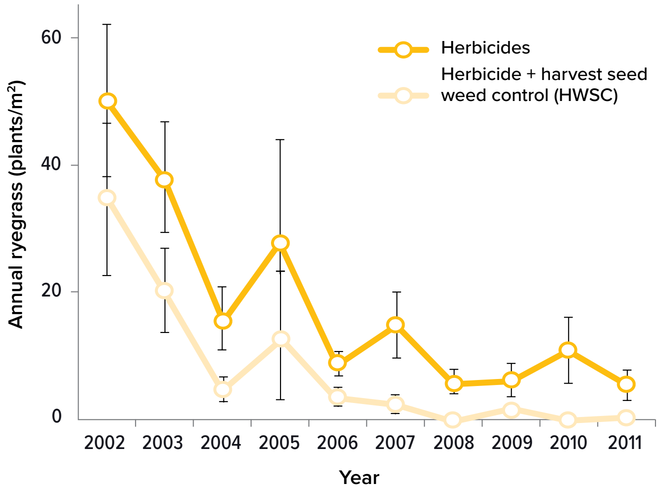
31 GRDC (2012) Fact Sheet — Herbicide resistance, Western Region, GRDC, https://grdc.com.au/GRDC-FS-HerbicideResistance

32 GRDC (2012) Fact Sheet — Herbicide resistance, Western Region, GRDC, https://grdc.com.au/GRDC-FS-HerbicideResistance

33 GRDC (2014) Integrated Weed Management Manual, Section 6 Profiles of common weeds of cropping, GRDC, www.grdc.com.au/IWMM

34 GRDC (2014) Integrated Weed Management Manual, Section 6 Profiles of common weeds of cropping, GRDC, www.grdc.com.au/IWMM

Figure 5: *Influence of the long-term (2002-2011) use of herbicides alone and herbicides plus harvest weed seed control (HWSC) on in-crop annual ryegrass plant densities in northern WA cropping fields.*[35]



NOTE: Capped bars represent the standard error values showing variation around the mean annual ryegrass populations in 17 fields (herbicides) or eight fields (herbicides plus HWSC).

MORE INFORMATION

GRDC Fact Sheet 'Wild Radish': www.grdc.com.au/GRDC-FS-WildRadishManagement

GRDC Hot Topic 'Wild Radish Control Options in WA': www.grdc.com.au/Media-Centre/Hot-Topics/Wild-radish-control-options-in-WA

GRDC 'Herbicide Resistance Testing': www.grdc.com.au/Media-Centre/Media-News/South/2014/04/Herbicide-resistance-testing-autumn-2014

DPIRD 'Wild radish': https://www.agric.wa.gov.au/grains-research-development/wild-radish

6.6 Wild radish

Figure 6: *Wild radish is a highly competitive weed in wheat crops and can cause yield losses of 10-90 percent.*

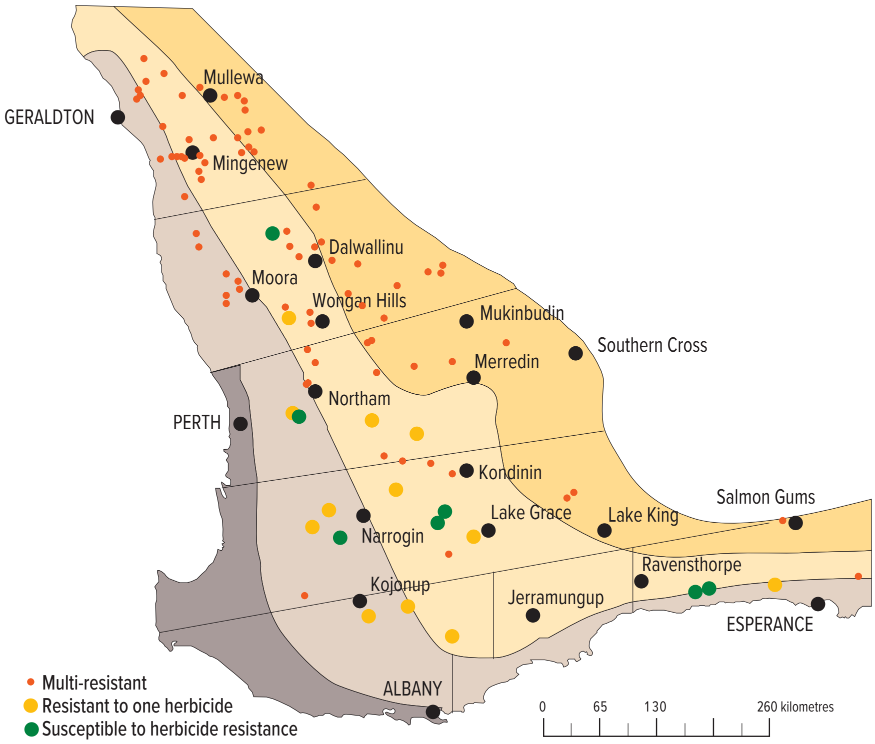
(SOURCE: GRDC)

35 Newman, P, DAFWA (2013) A systems approach to enhance the adoption of Integrated Weed Management techniques in the Northern Agricultural Region of WA, https://grdc.com.au/research/reports/report?id=1361

Wild radish is a highly competitive weed in wheat crops and can cause yield losses of 10-90 percent. It is an alternative host for several pests and diseases and it can lead to animal health problems when grazed.[36]

Wild radish with multiple herbicide resistance is also increasing in WA, as highlighted in Figure 7.

Figure 7: *Incidence of multi-resistant wild radish across WA's cropping zones.[37]*



SOURCE: AUSTRALIAN HERBICIDE RESISTANCE INITIATIVE, 2010 SURVEY

Wild radish is a prolific seeder and can emerge at any time of the year, providing there is sufficient soil moisture. But most seed germinates during autumn and winter.

Wild radish can produce seed in a very short time from germinations late in spring or during summer, its seedlings establish rapidly and it can grow relatively fast.

This weed is easily distributed as an impurity in hay, chaff and grain. Seed pods often break into segments that are similar in size to wheat seed and removing the contamination can be difficult.

Wild radish plants commonly shed pods before crop harvest in WA conditions, enabling the weed to persist in cropping systems.

Moisture levels of harvested grain can also be affected. In years when there are late rains and wild radish continues to grow and remain green after crop maturity, the moisture from the weed stems at harvest can raise crop grain moisture content above acceptable storage levels.

Wild radish has allelopathic activity and its extracts and residues can suppress germination, emergence and seedling growth of some crops and weeds.

Wild radish dormancy is controlled at three levels — the pod, the seed coat and the embryo.

36 DPIRD 'Wild radish' hub, 2017, https://www.agric.wa.gov.au/grains-research-development/wild-radish

37 DPIRD 'Wild radish' hub, 2017, https://www.agric.wa.gov.au/grains-research-development/wild-radish

The seed pod acts as a sponge to slow water uptake by the seed and contains alkaloids that protect it from microbial attack. This ensures the seed only germinates when there is enough soil moisture.

The seed coat acts as a second barrier to germination, with seeds only germinating once the seed coat has been ruptured to allow water to enter.

Once these physical barriers have broken down, the embryo senses the environment and allows germination only when conditions are right.

For buried seeds, conditions for germination are typically optimal in autumn and early winter in WA and there may be a secondary peak in spring.

The presence of the pod and seed coat mean fresh seed is unlikely to germinate until it has been weathered or physically damaged through harvest, tillage or stock grazing.

This explains why an 'autumn tickle' (or light cultivation) is so effective in promoting wild radish germination, provided there is enough moisture. It also explains why, in no-till systems, seed can remain dormant for longer and make other factors (such as predation and natural seed death) more important in driving down the weed seedbank.[38]

6.6.1 Herbicide resistance and wild radish

Populations of wild radish (mostly in WA) have developed resistance to a range of herbicide MOAs. Group B resistance is the most common, followed by Group F, but resistance also occurs in:

- Group B — sulfonylureas (for example, chlorsulfuron)
- Group B — sulfonamides (for example, metosulam)
- Group B — imidazolinones (for example, imazapic)
- Group C — triazines
- Group C — triazinones (for example, metribuzin)
- Group F — nicotinanalides (for example, diflufenican)
- Group I — phenoxies (2,4-D)
- Group M — glyphosate.[39]

A combination of IWM tactics can work to reduce or control populations of wild radish and help to manage herbicide resistance, as outlined in Table 6.

38 Peltzer, S (2016) Crop weeds: wild radish, DAFWA, https://agric.wa.gov.au/n/214

39 Peltzer, S (2016) Crop weeds: wild radish, DAFWA, https://agric.wa.gov.au/n/214

FEEDBACK

Table 6: Tactics to consider when developing an integrated plan to manage wild radish in WA cropping systems.[40]

Wild radish (*Raphanus raphanistrum*)		**Most likely % control (range)**	**Comments on use**
Agronomy	Herbicide tolerant crops	90 (80–99)	If growing canola in a wild radish infested area it is essential to use a herbicide resistant variety and associated herbicide package.
Tactic	Burning residues	70 (20–90)	In concentrated windrows. Burn when conditions are conducive to a hot burn.
Tactic	Inversion ploughing	98 (20-100)	Plough must be correctly 'set up' and used under the right conditions. Must use skimmers.
Tactic	Autumn tickle	45 (15–65)	Follow-up rain is needed for better response.
Tactic	Knockdown (non-selective) herbicides for fallow and pre-sowing control	80 (70–90)	Add a reliable herbicide spike for more reliable control. Late germinations will not be controlled.
Tactic	Selective post-emergent herbicides	90 (70–99)	Apply to young and actively growing weeds. Repeat if necessary to control late emerging weeds or survivors.
Tactic	Spray-topping with selective herbicides	80 (70–95)	Wild radish may regrow if there are late rains. Good for seedset control. Spray before embryo development for best results.
Tactic	Wiper technology	70 (50–80)	Has potential in low growing pulses such as lentils.
Tactic	Silage and hay – crops and pastures	80 (70–95)	Cut before embryo formation in developing wild radish seed (21 days after first flower). Graze or spray regrowth.
Tactic	Manuring, mulching and hay freezing	95 (90–100)	Brown manuring more efficient than green manuring and more profitable. Grazing before spraying to open sward will improve results. Hay freezing works well and is the most profitable manuring option in most cases.
Tactic	Grazing – actively managing weeds in pastures	70 (50–80)	Rotationally graze and use spray-grazing. Can also use slashing to improve palatability and reduce pasture growth rate in spring.
Tactic	Weed seed collection at harvest	75 (65–85)	Most reliable in early harvested paddocks.
Tactic	Sow weed-free seed	95 (90-100)	Very important as resistance in wild radish is increasing and introduction via crop seed is increasingly likely.

40 Peltzer, S (2016) Crop weeds: wild radish, DAFWA, https://agric.wa.gov.au/n/214

6.6.2 Control strategies for wild radish

The high and complicated seed dormancy of wild radish can make control of this weed difficult. Up to 70 percent of seed set in one season may not germinate for about 18 months.[41]

Exhausting the seedbank completely can take up to a decade of concerted weed management effort.

Any wild radish plants that survive to set seed results in the seedbank being replenished with a new wave of dormant seed.

Unlike annual ryegrass, wild radish seed survives for longer periods the deeper it is buried in the soil.

Wild radish control in WA cropping systems requires a multi-pronged approach consisting of:

- Applying in-crop herbicides twice
- Making the first application while weeds are small (two-leaf) at Zadoks Growth Scale GS12
- Using a second application no later than GS31 (first node)
- Ensuring excellent herbicide application
- Using narrow row spacing
- Considering east-west crop rows to out-compete weeds
- Using HWSC to destroy seedset of surviving weeds.[42]

Research in Geraldton in 2013 confirmed the value of a two-spray approach for wild radish control and improving wheat yields.

A trial was set up in wheat paddocks with a weed burden of 200 wild radish plants/ m^2 that were sprayed twice while small (at the two-leaf stage) with either Bromicide® 200 (Group C), Jaguar® (Group C + F) or Velocity® (Group H + C), followed by one of a range of herbicides at the five-leaf stage.

The twice sprayed areas out-yielded wheat plots sprayed only once (at the later stage) by an average of 0.4-0.5 tonnes/ha.[43]

Spraying wild radish only once at the five or six-leaf stage will typically not kill all plants and seed from the remainder will survive in the seedbank if not captured during harvest. Later sprays can also fail due to poor penetration of herbicide into the crop canopy.

Ensuring wheat crops can out-compete weeds using tactics such as higher seeding rates, narrow row spacing and east-west crop row orientation can help to reduce all in-crop weeds, including wild radish, annual ryegrass, wild oats and brome grass.

Using wheat rows that face east-west, rather than north-south, has been found to significantly reduce weed density in-crop in WA research trials, as shown in Table 7.

41 GRDC (2014) Hot Topic — Wild radish control options in WA, GRDC, https://grdc.com.au/Media-Centre/Hot-Topics/Wild-radish-control-options-in-WA

42 GRDC (2014) Hot Topic — Wild radish control options in WA, GRDC, https://grdc.com.au/Media-Centre/Hot-Topics/Wild-radish-control-options-in-WA

43 Lee, N (2014) Be the early bird on wild radish control, GRDC, https://grdc.com.au/Media-Centre/Media-News/West/2014/05/Be-the-early-bird-on-wild-radish-control

Table 7: Annual ryegrass seed production (seeds/m^2) in east-west or north-south orientated crops of wheat (2010) or wheat and barley (2011), with low or high seeding rates. Means for each factor within each trial are separated by least significant diff (Lsd), where NS indicates that the means were not different.[44]

Treatments	2010			2011		
	Merredin	Wongan Hills	Katanning	Merredin	Wongan Hills	Katanning
East-west	503	24	529	27	260	14113
North-south	910	300	465	125	6155	26276
Lsd (P<0.05)	331	36	NS	35	3469	1342
Barley	*	*	*	19	4420	16410
Wheat	*	*	*	146	4345	23378
Lsd (P<0.05)				18	NS	271
Low seeding rate	1032	130	151	119	5029	24087
High seeding rate	381	21	132	30	3736	15826
Lsd (P<0.05)	275	NS	NS	18	NS	271

"Treatment not included in trial.

Despite increasing herbicide resistance issues, some WA growers are able to keep weed seedbanks low.

Research shows the weed seedbank of wild radish can be reduced by up to 95 percent in five years if there is a concerted and integrated approach to weed control, including collection and destruction of weed seeds at harvest.[45]

44 GRDC (2014) Hot Topic — Wild radish control options in WA, GRDC, https://grdc.com.au/Media-Centre/Hot-Topics/Wild-radish-control-options-in-WA

45 GRDC (2014) Hot Topic — Wild radish control options in WA, GRDC, https://grdc.com.au/Media-Centre/Hot-Topics/Wild-radish-control-options-in-WA

MORE INFORMATION

WeedSmart '10-Point plan': http://www.weedsmart.org.au/10-point-plan/capture-weed-seeds-at-harvest/

GRDC 'Integrated Weed Management Manual': http://www.weedsmart.org.au/bulletin-board/integrated-weed-management-manual/

GRDC Hot Topic 'Integrated Weed Management in WA': https://grdc.com.au/Media-Centre/Hot-Topics/Integrated-Weed-Management-in-WA

6.7 Weed management at harvest

Figure 8: *The integrated Harrington Seed Destructor iHSD system is one way to destroy weed seeds at harvest by pulverising the chaff fraction as it leaves the harvester.*

(SOURCE: McIntosh & Son)

The seed from WA's major cropping weeds does not shatter before harvest and a large proportion is retained above crop height, enabling it to be removed at this time.

Common harvest weed seed control (HWSC) tactics that can be used to capture and/or destroy these seeds, lower the weed seedbank and help manage herbicide resistance issues include:

- Collecting chaff in chaff carts
- Using the Bale Direct system to collect straw and chaff as it exits the harvester
- Depositing chaff on narrow windrows for burning or livestock grazing the next autumn
- Using seed destruction technology to pulverise chaff fraction as it leaves the harvester
- Diverting chaff onto permanent tramlines (in controlled traffic farming systems) or into narrow rows.

Research shows that 75-85 percent of annual ryegrass seed and 85-95 percent of wild radish seed that enters the front of the header during the harvest operation can be collected using these HWSC methods. Some HWSC tactics have been shown to reduce annual ryegrass emergence in the following autumn by up to 60 percent. Combined with effective use of herbicides, HWSC can keep weed numbers at fewer than one plant per square metre — enabling earlier sowing each season.[46]

46 Walsh, M and Powles S, (2012) Harvest Weed Seed Control, Australian Herbicide Resistance Initiative, GRDC Update Papers, www.giwa.org.au

6.7.1 Stubble management and weed control

Figure 9: *Research and experience in WA indicates burning narrow windrows, rather than entire paddocks, can result in higher weed kill and less erosion risk.*

(SOURCE: GRDC)

Narrow windrow burning has been shown to control up to 99 percent of annual ryegrass and wild radish seed present in the windrow.

But narrow windrow burning efficacy is limited by the number of weed seeds that enter the front of the harvester, so total seed set control is in the range of 30 to 90 percent.

When considering burning stubbles, research has found that to kill annual ryegrass seed, a temperature of 400°C for 10 seconds is required. For complete kill of wild radish seed retained in pod segments, a temperature of 500°C for 10 seconds is needed.[47]

During traditional whole paddock stubble burning, the very high temperatures needed for weed seed destruction tend not to be sustained for long enough to kill most weed seeds. There are also risks of wind and water erosion with stubble burning.

By concentrating harvest residues and weed seed into a narrow windrow (of about 0.6-1.5 metres wide), fuel load is increased and the period of high temperatures extends to several minutes. This improves weed seed destruction.

Research and experience in WA indicates burning narrow windrows, rather than entire paddocks, can result in higher weed kill and less erosion risk.

Best results are typically achieved when windrows are burned during light cross or head winds (at a strength of about 5-10 km/hour), as the wind fuels the fire all the way to the soil surface where the bulk of weed seeds are located.

It is recommended to consult the local shire or fire warden for burning regulations, have firefighting equipment on hand and burn under ideal wind, temperature and humidity conditions.

A useful tool to determine suitability of burning conditions is the McArthur Grassland Fire Danger Index (GFDI). More information about this and the CSIRO Grassland Fire Danger Meter is available at http://www.csiro.au/en/Research/Environment/Extreme-Events/Bushfire/Fire-danger-meters/Grass-fire-danger-meter

47 Walsh, M and Newman, P (2007) Burning narrow windrows for weed seed destruction, Western Australian Herbicide Resistance Initiative/The University of Western Australia, ScienceDirect, http://ahri.uwa.edu.au/windrow-burning-a-good-place-to-start/

6.7.2 Timing of burns

Although burning early in the season is likely to achieve the best weed seed control, in many instances this is not practical due to weather conditions creating high risk of fire spread. As mentioned, it is recommended to consult the local shire or fire warden for burning regulations.

Premature removal of stubble can also increase erosion risk and reduce the efficiency of water conservation.

It is recommended to burn the outside two laps of the paddock first before starting on the rest of the paddock.

As a general rule-of-thumb, it is recommended burning is carried out with a grass fire index of:

- Less than 15 (will give a reasonable windrow burn)
- Ideally 8-10
- Not less than two (too cold and humid)
- No more than 15 (high risk of fire getting out of control).[48]

For narrow windrow burning, it can be important not to 'over-thresh' the straw at harvest — as this can become too fine and not burn well the next autumn.

It is recommended to light the windrows when the wind is at 90 degrees across, or diagonal to, the windrow (rather than parallel) as this prevents the fire developing a 'face' that can carry between the rows.

Another tip for burning windrows is to light up across the windrows every 75 m in good conditions — and closer as conditions cool down. The fires will tend to burn to meet each other.

It is advisable to start burning just on dark, when it is cooler, and plan to have the burning finished when the dew falls. This will limit stubble smouldering and flare-ups during the next day.

Summer rain will lower the burning temperature achieved in narrow windrows, but effective weed seed kill is possible if windrows are left for two weeks or more to dry before burning.

48 Walsh, M and Newman, P (2007) Burning narrow windrows for weed seed destruction, Western Australian Herbicide Resistance Initiative/The University of Western Australia, ScienceDirect, http://ahri.uwa.edu.au/windrow-burning-a-good-place-to-start/

MORE INFORMATION

GRDC 'Summer Fallow Weed Management Guide': www.grdc.com.au/GRDC-Manual-SummerFallowWeedManagement

GRDC Hot Topic 'Summer Fallow Weed Management': www.grdc.com.au/Media-Centre/Hot-Topics/Summer-fallow-weed-management

6.8 Summer weed control

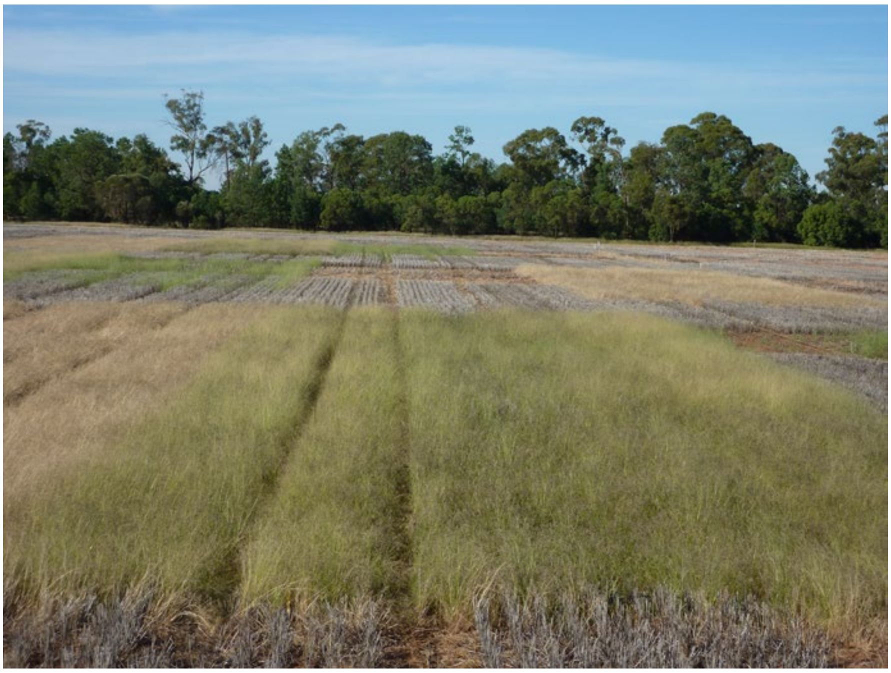


Figure 10: *Summer weeds are a scourge of WA crops.*

(SOURCE: DPIRD)

Summer weeds are best destroyed soon after emergence, when plants are small and actively growing. Weeds will stress fast in hot summer growing conditions and become more difficult to control.[49]

Summer weeds often germinate in winter crops after final post-emergent herbicides have been applied and then grow through to the summer fallow after the winter crop is harvested.

Tactics for effective summer weed control in WA include:

- Using a well-timed double-knock
- Determining rain fast periods for effective herbicide use
- Ensuring high water rates (at least 60 L/ha)
- Adding a surfactant and/or spraying oil to all post-emergent treatments (unless otherwise directed on the label)
- Avoiding treatment of stressed plants
- Considering residual herbicides (noting plant-back intervals when using pre-emergent herbicides)
- Not sowing susceptible crops before the plant-back period is complete
- Careful use of night spraying — consider inversion and drift conditions
- Considering WeedSeeker® and WeedIT® technologies.

Research has demonstrated weed management has the biggest impact on the amount of plant available water stored during a fallow period. Early and total control of summer weeds optimises soil moisture storage.[50]

49 GRDC (2014) Summer fallow weed management: A reference manual for grain growers and advisers in the southern and western grains regions of Australia, GRDC, www.grdc.com.au/GRDC-Manual-SummerFallowWeedManagement

50 Seymour, M, Kirkegaard, J. A, Peoples, M. B, White, P. F and French, R. J (2012) Break-crop benefits to wheat in Western Australia — insights from over three decades of research, CSIRO and DAFWA, http://www.publish.csiro.au/paper/CP14097.htm

Researchers have found 20-30 percent of moisture from summer rain events of more than 25 mm is typically still available in the soil in WA conditions at seeding if fallows are kept weed-free.[51]

As much as 30 mm (or even up to 80 mm on some soil types) of soil moisture can be available at the start of the growing season after weed-free fallows. Such deeply stored soil water can produce more grain per millimetre than from growing season rainfall.[52]

Growing season rainfall has dropped by 10 percent since the mid-1970s in WA's South West, with the amount and intensity of summer rain events (December-February) increasing during the same period.[53]

These rainfall trends highlight the importance of summer weed control to conserve soil moisture for use during below-average rainfall seasons. Results from modelling highlighting the profitability of summer weed control can be seen in Table 8.

Table 8: The percentage of years in WA in which modelled summer weed control was necessary, the percentage of those years where weed control was profitable, and the mean profit from summer weed control.[54]

Location	Propotion of years in which weed control was necessary	Proportion of years in which weed control was profitable	Mean profit
	(%)	(%)	($/ha)
Buntine	43	73	118
Mingenew	34	34	2
Morawa	43	88	156
Wongan Hills	45	44	17
Kellerberrin	48	82	129
Borden	53	58	34
Salmon Gums	62	92	213

Analysis shows summer weed control is profitable in 30-40 percent of years in lower rainfall areas and in 50-60 percent of years in wetter areas that have a higher crop yield potential. Research across southern Australia has also demonstrated an average $3.50 return in higher crop yields for every $1 spent on summer weed control.[55]

In all locations investigated, the mean return on investment from summer weed control was positive, but there were years in which control was not profitable.

Benefits from increased soil water storage at sowing were more likely to occur on soils with a larger water holding capacity and in drier locations.

Fallow weeds are more difficult to control in mid-summer, due to size and temperature stress, and require top label herbicide rates and/or a double-knock strategy.

It is advised to control summer weeds early and completely. The timing for effective control of various summer weed species is illustrated in Table 9.

51 Seymour, M, Kirkegaard, J. A, Peoples, M. B, White, P. F and French, R. J (2012) Break-crop benefits to wheat in Western Australia — insights from over three decades of research, CSIRO and DAFWA, http://www.publish.csiro.au/paper/CP14097.htm

52 Seymour, M, Kirkegaard, J. A, Peoples, M. B, White, P. F and French, R. J (2012) Break-crop benefits to wheat in Western Australia — insights from over three decades of research, CSIRO and DAFWA, http://www.publish.csiro.au/paper/CP14097.htm

53 Seymour, M, Kirkegaard, J. A, Peoples, M. B, White, P. F and French, R. J (2012) Break-crop benefits to wheat in Western Australia — insights from over three decades of research, CSIRO and DAFWA, http://www.publish.csiro.au/paper/CP14097.htm

54 Seymour, M, Kirkegaard, J. A, Peoples, M. B, White, P. F and French, R. J (2012) Break-crop benefits to wheat in Western Australia — insights from over three decades of research, CSIRO and DAFWA, http://www.publish.csiro.au/paper/CP14097.htm

55 GRDC (2016) Paddock Practices — Summer weed control, saving soil nitrogen and water to boost crop profits, GRDC, https://grdc.com.au/Media-Centre/GRDC-E-Newsletters/Paddock-Practices/Summer-weed-control-saving-soil-nitrogen-and-water-to-boost-crop-profits

Table 9: Latest spray timing for summer weeds to avoid seed set and problems with seeder blockages.[56]

Weed	Latest time to spray
Fleabane	Spray as early as possible after harvest; fleabane very difficult to control when large.
Melons	Important to distinguish between paddy melons and Afghan melons as paddy melons more difficult to kill and require higher herbicide rate. Spray pre-vine when plant is about saucer plate size.
Caltrop	Spray at flowering; very quickly develops viable seed so monitor closely. Alleopathic: can reduce wheat emergence.
Button grass	Spray from three-leaf to tillering; high rates required.
Wire weed/tar vine	Spray early; very difficult to control when large and causes seeder bloackages.
Iceplant	Spray while small. Becomes palatable and poisonous to stock as it dries off so if sprayed late remove stock.
Small crumbweed (mintweed/ goosefoot	Atrazine in many mixes can be used in southern areas to provide good control and ongoing residual control following summer rain.
Wild radish	Spray when pods are the thickness of a lead pencil.
Winter grasses – ryegrass	Spray when first heads fully emerged.

56 Seymour, M, Kirkegaard, J. A, Peoples, M. B, White, P. F and French, R. J (2012) Break-crop benefits to wheat in Western Australia — insights from over three decades of research, CSIRO and DAFWA, http://www.publish.csiro.au/paper/CP14097.htm