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GRDC
GROWNOTES™

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GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHICKPEA

SECTION 6

WEED CONTROL

FAQ

Weed control

Key messages

- Chickpeas are poor competitors with weeds because of slow germination and early growth.
- Weed control is essential if the chickpea crop is to make full use of in-crop rainfall and stored soil moisture and nutrients and to prevent weed seeds from contaminating the grain sample at harvest.
- Weed management should be planned well before planting, with chemical and non-chemical control options considered.
- There are limited options for pre-emergent and post-emergent weed control.
- Broadleaf weeds must be heavily targeted in the preceding crop and/or fallow. Always assess the broadleaf weed risk prior to planting.
- Chickpeas should always be planted into planned paddocks that have low weed populations.
- Chickpeas are late-maturing compared with other pulses; hence, crop-topping to prevent ryegrass and other weed seed-set is not possible.

Weeds are estimated to cost Australian agriculture AU$2.5-4.5 billion per annum, with winter cropping systems alone, baring a $1.3 billion cost (Photo 1). Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry (Table 1).

The latest recommendations from research in the high rainfall zones of southern Australia can be summed up as: sow a competitive crop early, on the first opening rain, with pre-emergent herbicide; sow the cleanest paddocks last; and implement harvest weed seed control. [1]

Photo 1: *Glyphosate resistant population of sowthistle show dead susceptible plants in the foreground.*

Photo: Graham Charles, Source: GRDC

1 WeedSmart. Gearing up to use pre-emergent herbicides. http://www.weedsmart.org.au/bulletin-board/gearing-up-to-use-pre-emergent-herbicides/

MORE INFORMATION

[Impact of weeds on Australian grain production]

[GRDC Weed management hub.]

Table 1: *Yield loss and revenue loss for residual weeds in all crops.*

Area	Residual weeds for all crops			
	Yield loss (t)	Revenue loss	Yield loss (t/ha)	Revenue loss (per hectare)
SA Mid-north – Lower Yorke Eyre	140,936	$37.5m	0.08	$21.67
SA Victorian Bordertown – Wimmera	95,724	$24.6m	0.05	$13.27
SA Victorian Mallee	72,895	$17.8m	0.02	$5.90
Victorian high-rainfall and Tasmanian grain	23,443	%5.9m	0.07	$18.60

Source: GRDC.

Early research indicates that chickpea seed yield can be reduced by 81% and straw yields by 63% when fields remained weed infested until harvest, compared with weed-free conditions throughout the growing season. The critical period of weed interference has been suggested to be between 35 and 49 days after emergence in chickpea. [2]

Weed control is essential if the chickpea crop is to make full use of stored summer rainfall, and in order to prevent weed seeds from contaminating the grain sample at harvest. Weed management should be planned well before planting, with chemical and non-chemical control options considered.

Chickpea crops are poor competitors with weeds because of their slow emergence and growth during winter. Kabuli chickpea competes poorly with weeds, particularly broad-leaved weeds such as radish, mustard, capeweed, and doublegee. Effective weed control is essential to prevent yield loss and to avoid the build-up of troublesome weeds in the rotation. Because of the slow growth and open canopy in chickpeas, narrow or wide row spacing (30 v. 70 cm) makes little difference to the chickpea plant's ability to compete with weeds. The weed-control strategy for growing a successful chickpea crop is based on substantially reducing the viable weed seedbank in the soil before the crop emerges, as post-emergence weed control options are limited. Broadleaf weed control options can be very limited in chickpeas, and this is a reason producers commonly give for not growing chickpeas.

The over-use of particular groups of herbicides through the rotation can lead to herbicide resistance, which has occurred in grass weeds and now some broadleaf weeds. To avoid herbicide resistance, weed management through the rotation should aim to minimise the need for herbicides, to avoid the overuse of any one group of herbicides and to use the least selective herbicide. Effective grass control in the chickpea crop has the benefit of reducing the need for selective grass herbicides in the following cereal year. [3]

Weed control is important because weeds can reduce yield and:

- rob the soil of valuable stored moisture
- rob the soil of nutrients
- cause issues at sowing time, restricting access for planting rigs (especially vine-type weeds such as melons, tar vine or bindweed, which wrap around tines)
- cause problems at harvest
- increase moisture levels of the grain sample (green weeds)
- contaminate the sample

2 Al-Thahabi, S. A., Yasin, J. Z., Abu-Irmaileh, B. E., Haddad, N. I., & Saxena, M. C. (1994). Effect of weed removal on productivity of chickpea (*Cicer arietinum* L.) and lentil (Lens culinaris Med.) in a Mediterranean environment. Journal of Agronomy and Crop Science, 172(5), 333-341.

3 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

VIDEOS

1. Grains research updates 2015: Problem weeds in Chickpea and Fallow.

- prevent some crops being grown where in-crop herbicide options are limited, i.e. broadleaf crops
- be toxic to stock
- carry disease
- host insects

Recent climate change impacts and implications

The rainfall patterns across south-eastern Australia over the past decade have been dominated by a strong and highly significant autumn rainfall decline. At the same time, the trend towards earlier seeding to improve Water Use Efficiency has meant that lower levels of grasses are germinating before sowing increasing the selection pressure on soil residual herbicides and post sowing herbicides. On Eyre Peninsula, there has been a selection for later germinating barley grass. [4]

6.1.1 Critical period for weed control

One study has found that chickpea must be kept weed-free between the five-leaf and full flowering stages (24–48 DAE) and from the four-leaf stage to beginning of flowering (17–49 DAE) in order to prevent >10% seed yield loss. The overall conclusion of this research was that chickpea should be weed free from 17–60 DAE and outside of this time-frame weeds are unlikely to significantly impact on yield. [5]

6.1 Integrated weed management (IWM)

There are very effective strategic and tactical options available to manage weed competition that will increase crop yields and profitability. Weeds with herbicide resistance are an increasing problem in grain cropping enterprises. The industry and researchers advise that growers adopt integrated weed management (IWM) to reduce the damage caused by herbicide-resistant weeds.

The following five-point plan will assist in developing a management plan in each and every paddock.

1. Review past actions and history.
2. Assess current weed status.
3. Identify weed management opportunities.
4. Match opportunities and weeds with suitably effective management tactics.
5. Combine ideas into a management plan. Use of a rotational plan can assist.

Integrated weed management (IWM) is a system for long-term weed management and is particularly useful for managing and minimising herbicide resistance.

An integrated weed management plan should be developed for each paddock or management zone.

In an IWM plan, each target weed is attacked using tactics from several tactic groups (see links below). Each tactic provides a key opportunity for weed control and is dependent on the management objectives and the target weed's stage of growth. Integrating tactic groups reduces weed numbers, stops replenishment of the seedbank, and minimises the risk of developing herbicide-resistant weeds.

The Grains Research and Development Corporation (GRDC) supports integrated weed management. Download the Integrated Weed Management Manual.

IWM tactics

- Reduce weed seed numbers in the soil
- Controlling small weeds
- Stop weed seed set

4 PIR.SA. Integrated weed management. Cropping weed management.

5 Mohammadi, G., Javanshir, A., Khooie, F. R., Mohammadi, S. A., & Zehtab Salmasi, S. (2005). Critical period of weed interference in chickpea. Weed research, 45(1), 57-63.

- Reduce weed seed numbers in the soil
- Hygiene - prevent weed seed introduction
- Agronomic practices and crop competition

Successful weed management also relies on the implementation of the best agronomic practices to optimise crop growth. Basic agronomy and fine-tuning of the crop system are the important steps towards weed management.

There are several agronomic practices that improve crop environment and growth, along with the crop's ability to reduce weed competition. These include crop choice and sequence, improving crop competition, planting herbicide-tolerant crops, improving pasture competition, using fallow phases, and controlled traffic or tramlining. [6]

Because management of herbicide resistance is case specific, it is difficult to prescribe 'recipes' for how to manage a problem. Instead, you need to understand your situation and choose from a range of methods, such as those outlined below.

Choose a method from the IWM tool box. Consider how these might fit into your farming system and seek advice from your local agronomist. These methods allow you to keep weed populations under control and delay the onset of resistance.

Method 1. Autumn tickle: use light scarification to stimulate weed germination, then spray (paying attention to rotating your chemical groups) before sowing.

Method 2. Barley for weed control: barley is competitive against weeds and use of pre-emergence herbicides is effective. Its shorter growing season also allows for pre-sowing weed control.

Method 3. Catching: use a bin attachment on your harvester to collect weed seed. Then burn the seed. Harvest weed seed management strategies are increasingly being implemented.

Method 4. Crop-topping: Use a non-selective herbicide (paraquat-based) to mature or near-mature crops to reduce weed seed set. However, crop-topping is difficult to implement in chickpeas and is not common practice. Crop-topping in pulse crops can be very effective—weed wiping weeds in lentil crops as a prelude to crop-topping is also effective.

Method 5. Cultivation: Use cultivation to kill germinated weeds.

Method 6. Delayed sowing: Delay sowing for two or more weeks so that additional weeds can be killed by non-selective herbicide. However, yield penalties need to be considered before altering sowing dates.

Method 7. Double-knock strategy: Use a glyphosate application followed by paraquat-based application to control weeds before sowing.

Method 8. Harvest low, no spread, burn: This method has three stages: harvest the crop lower than usual, put the residue (containing weeds) into narrow rows for burning (allows for hotter fire).

Method 9. Hay: Use crop for hay. Trials in southern Australia showed that hay making was most effective—reducing seeds per square metre. Hay cutting alone doesn't guarantee success; you also need to graze or spray-top after it re-shoots to prevent seed on regrowth, and take care when feeding hay out that ryegrass seeds aren't spread to other paddocks.

Method 10. Heavy grazing: Weed seed set is reduced by timely intense grazing of paddocks not sown to crop (and seedbank is reduced).

Method 11. High crop sowing rate: Used to produce a higher crop plant density to reduce yield loss due to weeds and to suppress weed seed production.

6 DAFWA. (2016). Crop weeds: Integrated Weed Management (IWM). https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm

MORE INFORMATION

[Herbicide resistance and integrated weed management (iwm) in crops and pasture monitoring tools](#)

[GRDC IWM Hub.](#)

[Weed Seed Wizard](#)

Method 12. Manuring: Use the crop for 'green manure' before it matures to prevent weed seed set and increase organic matter.

Method 13. Mechanical pasture top: Slash the pasture before weed maturity.

Method 14. Spray-topping: Use a low-rate of non-selective herbicide applied to pastures to reduce weed seed set.

Method 15. Careful consideration of rotations (pasture phase instead of continuous cropping). A two-year (or more) pasture phase treated to reduce weeds before it goes back into crop. A pasture phase longer than two years is very effective (one year is not enough to reduce seedbank). It should be noted that it is not the pasture phase itself that helps to manage weeds, but it is what the phase allows you to do in addition, e.g. grazing and pasture topping. Crop rotations need to be managed carefully. Continuous cropping requires strong planning and management practices.

Method 16. Stubble burning: Stubble is burned in autumn to reduce viable weed seeds (but reduces organic matter).

Method 17. Windrowing for weed control: cutting crop near to full maturity and leave to dry in rows to reduce seed shatter (usually done in canola). Can be done in other crops but earlier than usual and lower than normal. [7]

Weed Seed Wizard

The Weed Seed Wizard helps growers to understand and manage weed seedbanks on farms across Australia's grain-growing regions.

Weed Seed Wizard is a computer simulation tool that uses paddock-management information to predict weed emergence and crop losses. Different weed-management scenarios can be compared to show how different crop rotations, weed control techniques, and irrigation, grazing and harvest management tactics can affect weed numbers, the weed seedbank and crop yields.

The Wizard uses farm-specific information, and users enter their own farm-management records, their paddock soil type, local weather and one or more weed species. The Wizard has numerous weed species to choose from, including annual ryegrass, barley grass, wild radish, wild oat, brome grass and silver grass in the southern states.

A free download is available from: https://www.agric.wa.gov.au/weed-seed-wizard-0.

The Weed Seed Wizard is helping farm advisers and their grain-grower clients make decisions that will reduce weed seedbanks and the cost of controlling those weeds.

6.2 Planting control strategies

Pulses grown in rotation with cereal crops offer farmers opportunities to easily control grassy weeds with selective herbicides that cannot be used in the cereal years. An effective kill of grassy weeds in the pulse crop will reduce root disease carry over and provide a "break crop" benefit in the following cereal crop. Grass control herbicides are now available which will control most grassy weeds in pulses. Volunteer cereals can also be controlled with some of these herbicides. Simazine alone and in mixtures with trifluralin in pulse crops can be used to control some other grasses (such as silver grass) that are not readily controlled by the specific grass herbicides. [8]

Do not sow chickpea into a pasture paddock where broadleaf weed pressure will be high. For best results, sow chickpea into paddocks with low broadleaf weed populations. Make the most of opportunities to reduce broadleaf weeds in the preceding crop when weed control is likely to be more effective, cheaper, and cause

7 Agriculture Victoria. HERBICIDE RESISTANCE AND INTEGRATED WEED MANAGEMENT (IWM) IN CROPS AND PASTURE MONITORING TOOLS. http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

8 GRDC Grain Legume Handbook – Weed control.

less damage to that crop. Delaying chickpea sowing until after a germination of broadleaf weeds also assists in areas or seasons where this is possible. [9]

The use of rotations that include both broadleaf and cereal crops may allow an increased range of chemicals—say three to five MOAs—or non-chemical tactics such as cultivation or grazing.

Strategic cultivation can provide control of herbicide-resistant weeds and those that continue to shed seed throughout the year. It can be used to target large, mature weeds in a fallow, for inter-row cultivation in a crop, or to manage isolated weed patches in a paddock. Take into consideration the size of the existing seedbank and the increased persistence of buried weed seed, but never rule it out. [10]

It is important that broadleaf populations are considered when selecting a paddock for chickpea production. Broadleaf weeds should be heavily targeted in the preceding wheat or barley crop or fallow, bearing in mind the herbicide residual effects. Paddocks with severe broadleaf weed infestation should be avoided. [11] If broadleaf weeds that are not well-controlled by registered broadleaf herbicides are present, then consider altering the cropping rotation until the weed species is controlled.

6.2.1 Managing wild oats in chickpeas

Wild oats (*Avena fatua* and *A. ludoviciana*) represent a large cost to cropping (Photo 2). Wild oats are highly competitive and when left uncontrolled can reduce wheat yields by up to 80%. Greatest yield loss occurs when the wild oat plants emerge at the same time as the crop. Chickpea rotations provide an opportunity to control wild oats, which is otherwise a costly weed in a wheat-based system. However, care should be taken to ensure that surviving weeds are identified and removed to reduce the chance of resistance developing. Herbicide-resistant wild oats are becoming a key threat to sustainable farming systems. Herbicide resistance in wild oats poses management problems in any crop where these herbicides have previously been relied upon, but the threat appears greater to chickpea production. Chickpeas are most at risk because they are a poorly competitive crop and often produced on wide rows. In addition, they have only Group A herbicides available for post-emergent control. Effective use of crop rotation must be made to assist in management of wild oats. This will allow the use of the winter fallow and other effective herbicides (differing MOAs including knockdowns) as well as improved crop competition to reduce seed-set of wild oats. [12] Factor® (butroxydim) was not effective as a knockdown for wild oats in chickpeas. Mixtures of Verdict® (haloxyfop) plus Status® (clethodim) or 500 mL/ha of Status® proved the most effective mixes for knockdown control of wild oats. [13] None of the newer herbicides are registered for wild oat control.

9 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

10 GRDC (2012) Herbicide resistance. Cropping with herbicide resistance. GRDC Hot Topics, http://www.grdc.com.au/Media-Centre/Hot-Topics/Herbicide-Resistance

11 DAFF (2012) Chickpea—weed management. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/weed-management

12 Storrie (2007) Managing wild oats in chickpeas—our practices must change. Northern Grower Alliance, http://www.nga.org.au/results-and-publications/download/45/australian-grain-articles/weeds-1/wild-oats-inchickpeas-tip-of-the-iceberg-september-2007.pdf

13 GRDC Update Papers. 2015. NGA Chickpea herbicide trials 2014. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/NGA-Chickpea-herbicide-trials-2014

Photo 2: *Wild oats have a large ligule with no auricles and the leaves tend to be hairy with a slight bluish hue. The emerging leaf is rolled. Wild oats tend to grow in discrete patches at low to moderate densities (up to 100 plants/m^2) and can be confused with brome grass in the seedling stage.*

Source: DAFWA, Photo: Syngenta.

6.2.2 Row spacing

Why do narrow rows yield more?

- reduced weed competition
- early canopy closure
- increased light interception
- reduced evaporation
- reduced competition between crop plants within the row

The simple reason for reduced ryegrass seed set in narrow row spacing is light interception by the crop (Photo 3). In the '90s, when no-till was being adopted, most growers had little choice but to adopt wide row spacing. Stubble retention and no-till go hand-in-hand, so burning for stubble handling became frowned upon for good reason. Harvester capacity was limited, so harvesting low was out of the question, and seeders struggled to handle stubble. Wide rows were the only option.

Photo 3: *Narrow v. wide row canola in 2009. No light reaching the ground in narrow row spacing plots. Ryegrass germinated about when this photo was taken and was not sprayed due to crop safety concerns. Very low ryegrass seed set in the 9 and 18 cm row spacing treatments (top) compared to 27 and 36 cm treatments (bottom).*

Source: UWA.

In 2016 we have harvesters that can harvest low (10–15 cm) and cut and spread the straw evenly. We also have seeders that can handle more stubble than their predecessors. Many growers in regions that regularly achieve wheat yields of 3 to 4 t/ha have successfully adopted 7" (19 cm) row spacing with both tine and disc machines. It's less convenient than wide rows and costs more, but the benefits outweigh the negatives.

WA trials have been conducted exploring the effect of row spacing in weed control for a variety of crops. Tines were removed from the combine as row spacing widened. In a nutshell, narrow row spacing yielded more and had fewer ryegrass (Tables 2 and 3).

Table 2: *Crop yield (kg/ha).*

Year	Crop	Row Spacing			
		9 cm	18 cm	27 cm	36 cm
2003	Wheat	3210	3317	3099	3049
2004	Wheat	1823	1825	1760	1560
2005	Field pea	1995	2024	1761	1710
2006	Wheat	2585	2631	2358	2216
2007	Barley	366	385	394	441
2008	Chemical fallow	*	*	*	*
2009	Canola	929	887	832	766
2010	Wheat	1273	1077	988	1031
2011	Wheat	2140	2058	1969	1975
2012	Chickpea	176	148	119	141
2013	Wheat	2083	2021	2196	2035

Source: UWA.

Table 3: *Annual ryegrass seed (per m^2) at harvest.*

Year	Crop	Row Spacing			
		9 cm	18 cm	27 cm	36 cm
2003	Wheat	324	296	702	382
2004	Wheat	318	312	757	1001
2005	Field pea	375	558	1930	1581
2006	Wheat	14	18	29	27
2007	Barley	25	54	424	789
2008	Chemical fallow	*	*	*	*
2009	Canola	140	319	3056	3468
2010	Wheat	17	24	36	173
2011	Wheat	159	162	334	552
2012	Chickpea	60	50	135	287
2013	Wheat	2	1	51	171

Source: UWA.

MORE INFORMATION

UWA – Narrow Row spacing – more crop, fewer weeds.

VIDEOS

2. AHRI insight #70: Narrow row spacing, more crop, fewer weeds.

IN FOCUS

Chemical and Non-chemical Weed Control in Wide Row Chickpeas

Organic crops are on the increase worldwide and weed control is one of the main problems since chemicals cannot be used. Wide row lupin sowing systems (greater than 50 cm wide rows) are becoming common and this allows growers to control interrow weeds by inter-row cultivation for organic crops or spraying non-selective herbicides using shielded sprayers. In this study, inter-row shielded spraying was found to be the most effective treatment for annual ryegrass control in the 66 cm wide rows, but future herbicide resistance will be a major limitation. With shielded spraying, some form of intra-row weed control will still be necessary to significantly reduce weed seed set. Automatic tractor steering control would also be essential for commercial growers to adopt shielded spraying. In 2006, inter-row cultivation reduced annual ryegrass biomass by 63% and the number of annual ryegrass heads by 43%. To be most effective, it is suggested that inter-row cultivation should be done relatively early while the weeds are small, and when the soil is relatively warm and dry with rain not predicted for a day or two. In 2006 and 2007, inter-row shielded spraying with glyphosate gave the best ryegrass control averaging 94%. Weed seed head trimming or cutting weeds above the crop prior to weed seed maturity may be a useful non-chemical method to reduce the number of weed seeds set if the weed seed is above the crop canopy and the cutting height is well controlled. Indian hedge mustard (Sisymbrium orientale) 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 in chickpeas. Lupin and chickpea grain yield was slightly reduced by trimming in 2005, but with improved height control did not reduce yields in 2006. Given the difficulties in controlling weeds by the growers due to widespread development of herbicide resistance in these weeds, this novel non-chemical way of weed control is a viable promising option to reduce the soil weed seed bank. [14]

6.3 Herbicides explained

6.3.1 Residual and non-residual

Residual herbicides remain active in the soil for an extended period (months) and can act on successive weed germinations. Residual herbicides must be absorbed through the roots or shoots, or both. Examples of residual herbicides include isoxaflutole, imazapyr, chlorsulfuron, atrazine, and simazine.

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall and irrigation, temperature, and the herbicide's characteristics. The persistence of herbicides will affect the enterprise's sequence (a rotation of crops, e.g. wheat–barley–chickpeas–canola–wheat).

Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and they are quickly deactivated in the soil. They are either

14 Riethmuller, G. P., Hashem, A., & Pathan, S. M. (2009). Chemical and non-chemical weed control in wide row lupins and chickpeas in Western Australia. Australian Journal of Multi-disciplinary Engineering, 7(1), 15-26.

broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

6.3.2 Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, whereas pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. [15]

6.4 Mode of Action (MOA)

Herbicides have been classified into a number of 'groups'. The group refers to the way a chemical works—their different chemical make-up and mode of action (see Herbicide Mode of Action Groups, for a full list of options).

Resistance has developed primarily because of the repeated and often uninterrupted use of herbicides with the same mode of action. Selection of resistant strains can occur in as little as 3–4 years if attention is not paid to resistance management. Remember that the resistance risk remains for products having the same MOA. If you continue to use herbicides with the same MOA and do not follow a resistance-management strategy, problems will arise.

6.4.1 MOA labelling

In order to facilitate management of herbicide-resistant weeds, all herbicides sold in Australia are grouped by MOA. The MOA is indicated by a letter code on the product label. The MOA labelling is based on the resistance risk of each group of herbicides. Australia was the first country to introduce compulsory MOA labelling on products, and the letters and codes used in Australia are unique. Labelling is compulsory and the letters and codes reflect the relative risk of resistance evolving in each group. Since the introduction of MOA labelling in Australia, other countries have adopted MOA classification systems; however, caution is advised if cross-referencing MOAs between Australia and other countries, as different classification systems are used. The herbicide MOA grouping and labelling system in Australia was revised in 2007. This is the first major revision of the classification system since its introduction.

The original groupings were made based on limited knowledge about MOAs. Groupings have been changed to improve the accuracy and completeness of the MOAs to enable more informed decisions about herbicide rotation and resistance management. The general intent of groups based on their risk has not changed.

6.4.2 Grouping by mode of action and ranking by resistance risk

Growers and agronomists are now better assisted to understand the huge array of herbicide products in the marketplace in terms of MOA grouping and resistance risk by reference to the MOA chart. All herbicide labels now carry the MOA group clearly displayed, such as:

Group	**G**	**Herbicide**

Know your herbicide groups to make use of this labelling.

Not all MOA groups carry the same risk for resistance development; therefore, specific guidelines for Groups E, G, H, N, O, P, and R have not been developed because there are no recorded cases of weeds resistant to members of these groups in Australia.

15 T McGillion, A Storrie (Eds) (2006) Integrated weed management in Australian cropping systems—A training resource for farm advisors. Section 4: Tactics for managing weed populations. CRC for Australian Weed Management, Adelaide, https://grdc.com.au/__data/assets/pdf_file/0030/48639/iwmmc-pdf.pdf.pdf

Products represented in Group A (mostly targeted at annual ryegrass and wild oats) and Group B (broadleaf and grass weeds) are HIGH RESISTANCE RISK herbicides, and specific guidelines are written for use of these products in winter cropping systems.

Specific guidelines are also available for the MODERATE RESISTANCE RISK herbicides: Group C (annual ryegrass, wild radish and silver grass), Group D (annual ryegrass and fumitory), Group F (wild radish), Group I (wild radish and Indian hedge mustard), Group J (serrated tussock and giant Parramatta grass), Group L (annual ryegrass, barley grass, silver grass and cape weed), Group M (annual ryegrass, barnyard grass, fleabane, liverseed grass and windmill grass), Group Q (annual ryegrass), and Group Z (wild oats and winter grass).

Specific guidelines for Group K have been developed due to the reliance on this MOA to manage annual ryegrass, and the possibility of future resistance development. [16]

6.4.3 Specific guidelines for Group A herbicides

The following charts have been compiled from chemical labels on the APVMA web site and PIRSA Spraying charts and in consultation with chemical companies. (Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	A	Herbicide

High resistance risk.

Group A resistance exists in Australia in the grass weeds, including annual ryegrass, wild oats, phalaris, brome grass, crab grass, goose grass and barley grass. Resistance has developed in broadacre and vegetable situations.

Research has shown that as few as six applications to the same population of annual ryegrass can result in the selection of resistant individuals. A population can go from a small area of resistant individuals to a whole-paddock failure in one season.

Fops, dims, and dens are Group A herbicides and carry the same high resistance risk. Where a Group A herbicide has been used on a particular paddock for control of any grass weed, avoid using a Group A herbicide to control the same grass weed in the following season, irrespective of the performance it gave.

Frequent application of Group A herbicides to dense weed populations is the worst scenario for rapid selection of resistance.

Where resistance to a member of Group A is suspected or known to exist, there is a strong possibility of cross-resistance to other Group A herbicides. Therefore, use other control methods and herbicides of other MOA groups in a future integrated approach.

The above recommendations should be incorporated into an integrated weed management (IWM) program. In all cases, try to ensure that surviving weeds from any treatment do not set and shed viable seed. Keep to integrated strategies, including rotation of MOA groups.

16 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 4: *Active ingredients of Group A MOAs.*

Chemical family	Active constituent (first registered trade name)
Group A. Inhibitors of acetyl coA carboxylase (inhibitors of fat synthesis/ACCase inhibitors)	
Aryloxyphenoxypropionates (fops)	Clodinaafop (Topik®), cyhalofop (Barnstorm®), diclofop (Cheetah® Gold, Decision®*, Hoegrass®, Tristar® Advance*), fenoxaprop (Cheetah® Gold*, Tristar® Advance*, Wildcat®), fluazifop (Fusilade®, Fusion®*), haloxyfop (Motsa®*, Verdict®), propaquizafop (Shogun®), quizalofop (Targa®)
Cyclohexanediones (dims)	Butroxydim (Falcon®, Fusion®*), clethodim (Motsa®*, Select®), profoxydim (Aura®), sethoxydim (Cheetah® Gold*, Decision®*, Sertin®), tepraloxydim (Aramo®), tralkoxydim (Achieve®)
Phenylpyrazoles (dens)	Pinoxaden (Axial®)

*This product contains more than one active constituent.

6.4.4 Specific guidelines for Group B herbicides

(Source: CropLife Australia, 'Herbicide Resistance Management Strategies—September 2011'.)

Group	B	Herbicide

High resistance risk.

Group B resistance exists in Australia in the grass weeds, annual ryegrass, barley grass, brome grass, wild oats, and crab grass and in at least 16 broadleaf weeds including: wild radish, common sowthistle, climbing buckwheat, turnip weed, wild mustard, Indian hedge mustard, prickly lettuce, wild turnip, and African turnip weed. Resistance has developed in broadacre, rice, and pasture situations. With respect to rice, three broadleaf weeds have been discovered: dirty dora, arrowhead, and starfruit.

Research has shown that as few as four applications to the same population of annual ryegrass can result in the selection of resistant individuals and as few as six applications for wild radish. A population can go from a small area of resistant individuals to a whole paddock failure in one season.

Avoid applying more than two Group B herbicides in any four-year period on the same paddock.

Broadleaf weed control

If a pre-emergent application is made with a Group B herbicide for broadleaf weed control, monitor results and, if required, apply a follow-up spray with a non-Group B herbicide for control of escapes and to reduce seed-set.

If a post-emergent application is made with a Group B herbicide for broadleaf weed control, it should preferably be as an APVMA-approved tank-mix with another MOA that controls or has significant activity against the target weed. If no APVMA-approved tank-mix is available, then monitor results and if required, apply a follow-up spray with a non-Group B herbicide for control of escapes and to reduce seed-set.

A Group B herbicide may be used alone on flowering wild radish only if a Group B herbicide has not been previously used on that crop.

Grass-weed control

If there are significant escapes following the herbicide application, consider using another herbicide with a different mode of action or another control method to stop seed-set.

Table 5: *Active ingredients for Group B MOAs.*

Chemical family	Active constituent (first registered trade name)
Group B. Inhibitors of acetolactate synthase (ASL inhibitors)	
Sulfonylureas (SUs)	Azimsulfuron (Gulliver®), bensulfuron (Londax®), chlorsulfuron (Glean®), ethoxysulfuron (Hero®), foramsulfuron (Tribute®), halosulfuron (Sempra®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®, Harmony®*M, Trounce®*, Ultimate Brushweed®* Herbicide), prosulfuron (Casper®*) rimsulfuron (Titus®), sulfometuron (Oust®), sulfosulfuron (Monza®), thifensulfuron (Harmony®*M), triasulfuron (Logran®, Logran® B-Power*) tribenuron (Express®), trifloxysulfuron (Envoke®, Krismat®*)
Imidazolinones (imis)	Imazamox (Raptor®, Intervix®*), imazapic (Flame®, Midas®*, OnDuty®*), imazapyr (Arsenal Xpress®*, Midas®*, OnDuty®*, Intervix®*, Lightning®*), imazethapyr (Spinnaker®, Lightning®*)
Triazolopyrimidines (sulfonamides):	Flumetsulam (Broadstrike®), florasulam (Conclude®*, Torpedo®*, X-Pand®*), metosulam (Eclipse®), pyroxsulam (Crusader®)
Pyrimidinylthiobenzoates	Bispyribac (Nominee®), pyrithiobac (Staple®)

*This product contains more than one active constituent.

6.4.5 Specific guidelines for Group C herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	**C**	**Herbicide**

Moderate resistance risk.

Group C resistance exists in Australia in the weeds annual ryegrass, wild radish, liverseed grass, silver grass, stinging nettles, and barnyard grass. Resistance has developed in broadacre, horticultural, and non-crop situations.

CropLife Australia gives specific guidelines for the use of Group C herbicides in TT canola and in winter legume crops, following increasing reports of resistance development.

Avoid using Group C herbicides in the same paddock in consecutive years. Growing TT canola in a paddock treated with triazine herbicides in the previous season is a high resistance risk and is not recommended.

Watch and record for weed escapes, especially in paddocks with a long history of Group C use.

Consult the 'Integrated Weed Management Strategy for TT Canola' for further details. The resistance status of the 'at-risk' weeds should be determined prior to sowing. Always use the label rate of herbicide, whether a single active ingredient (e.g. bromoxynil) or combination of active ingredients is applied (e.g. bromoxynil/MCPA, pyrasulfotole/bromoxynil). Apply to weeds at the labelled growth stage and ensure that no weeds set and shed viable seed. To prevent seed-set, control survivors with a herbicide of different MOA from Group C, or use another weed-management technique.

Table 6: *Active ingredients in Group C MOAs.*

Chemical family	Active constituent (first registered trade name)
Group C. Inhibitors of photosynthesis at photosystem II (PS II inhibitors)	
Triazines	Ametryn (Amigan®*, Primatol Z®, Gesapax® Combi*, Krismat®), atrazine (Gesaprim®, Gesapax® Combi*, Primextra® Gold*), cynazine (Bladex®), prometryn (Gesagard®, Cotoguard®*, Bandit®*), propazine (Agaprop®), simazine (Gesatop®) terbuthylazine (Terbyne®), terbutryn (Amigan®*, Igran®, Agtryne® MA*)
Triazinones	Hexazinone (Velpar® L, Velpar® K4*), metribuzin (Sencor®)
Uracils	Bromacil (Hyvar®, Krovar®*), terbacil (Sinbar®)
Pyridazinones	Chloridazon (Pyramin®)
Phenylcarbamates	Phenmedipham (Betanal®)
Ureas	Diuron (Karmex®, Krovar®*, Velpar® K4*), fluometuron (Cotoran®, Cotoguard®*, Bandit®*), linuron (Afalon®), methabenzthiazuron (Tribunil®), siduron (Tupersan®), tebuthiuron (Graslan®)
Armides	Propanil (Stam®)
Nitriles	Bromoxynil (Buctril®, Buctril® MA*, Barrel®*, Jaguar®*, Velocity®*, Flight®*), ioxynil (Totril®, Actril DS*)
Benzothiadiazinones:	Bentazone (Basagran®, Basagran® M60*)

*This product contains more than one active constituent.

6.4.6 Specific guidelines for Group D herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	D	Herbicide

Moderate resistance risk.

Resistance to Group D herbicides is known for an increasing number of populations of annual ryegrass and fumitory. Resistance has generally occurred after 10–15 years of use of Group D herbicides.

Where possible, avoid the use of Group D herbicides on dense ryegrass populations. Consider using alternative methods of weed control to reduce weed numbers before applying herbicides.

Rotate with herbicides from other MOA. For annual ryegrass, consider rotating trifluralin with products such as Boxer Gold®.

These recommendations should be incorporated into an IWM program. Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups.

Table 7: *Active ingredients of Group D MOAs.*

Chemical family	Active constituent (first registered trade name)
Group D. Inhibitors of microtubule assembly	
Dinitroanilines (DNAs)	Oryzalin (Surflan®, Rout®*), pendimethalin (Stomp®), prodiamine (Barricade®), trifluralin (Treflan®)
Benzoic acids	Chlorthal (Dacthal®, Prothal®*)
Benzamides	Propyzamide (Kerb®)
Pyridines	Dithiopyr (Dimension®), thiazopyr (Visor®)

*This product contains more than one active constituent.

6.4.7 Specific guidelines for Group F herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	F	Herbicide

Moderate resistance risk.

Resistance to Group F herbicides is known for a small number of populations of wild radish. Resistance has generally occurred after a long history of use of Group F herbicides. The number of populations with Group F resistance is increasing following increased use of these herbicides.

Group F includes herbicides that reduce carotenoid biosynthesis through inhibition of phytoene desaturase (PDS).

Avoid applying Group F herbicides in any two consecutive years unless one application is a mixture with a different MOA that is active on the same weed, or a follow-up spray is conducted (using a different MOA) to control escapes. Always use the label rate of herbicide, whether a single active ingredient (e.g. diflufenican) or combination of active ingredients is applied (e.g. diflufenican/MCPA, picolinafen/MCPA). Apply to weeds at the labelled growth stage and ensure that no weeds set and shed viable seed. To prevent seed-set, control survivors with a herbicide of different MOA from Group F, or use another weed-management technique.

If applicable, apply a follow-up spray with a non-Group F herbicide for control of escapes and to reduce seed-set. Aim to ensure that surviving weeds from any treatment do not set and shed viable seed.

These recommendations should be incorporated into an IWM program. Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies including rotation of MOA groups.

Table 8: *Active ingredients for Group F MOAs.*

Chemical family	Active constituent (first registered trade name)
Group F. Bleachers: Inhibitors of carotenoid biosynthesis at the phytoenede saturase step (PDS inhibitors)	
Nicotinanilides	Diflufenican (Brodal®, Jaguar®*, Tigrex®*, Chipco Spearhead®*)
Picolinamides	Picolinafen (Paragon®*, Sniper®, Flight®)
Pyridazinones	Norflurazon (Solicam®)

*This product contains more than one active constituent.

6.4.8 Specific guidelines for Group I herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	I	Herbicide

Moderate resistance risk.

Resistance to Group I herbicides is known for a number of populations of wild radish and Indian hedge mustard. Resistance has occurred after a long history of use of Group I herbicides. The number of populations with Group I resistance is increasing.

It is of particular concern that in addition to Group I resistance in wild radish, which is the most important broadleaf weed in broadacre agriculture, some populations are cross-resistant to other MOAs, e.g. Group F herbicides, which can be important for control of wild radish in lupins where other selective, non-Group I options are limited. Because of the long soil life of wild radish seed, measures to reduce the return of seed to the soil would be useful for this weed. Wild radish seed that is confined to the top 5 cm soil has a shorter life than seed buried deeper.

As a rule, in situations of high resistance risk:

- Avoid applying two applications of Group I herbicides alone onto the same population of weeds in the same season.
- Where possible, combine more than one MOA in a single application. Each product should be applied at rates sufficient for control of the target weed alone to reduce the likelihood of weeds resistant to the Group I herbicide surviving.

These recommendations should be incorporated into an IWM program. Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups.

Table 9: *Active ingredients of Group I MOAs.*

Chemical family	Active constituent (first registered trade name)
Group I. Disruptors of plant cell growth (synthetic auxins)	
Phenoxycarboxylic acids (phenoxys)	2,4-D (Amicide®, Actril DS®*, Pyresta®*), 2,4-DB (Trifolamine®), dichlorprop (Lantana 600®), MCPA (MCPA, Buctril® MA*, Banvel M®*, Conclude®*, Midas®*, Paragon®*, Tigrex®*, Barrel®*, Tordon 242®*, Basagran® M60*, Chipco Spearhead®*, Agtryne® MA*, Precept®*, Flight®*) MCPB (Legumine®), mecoprop (Mecopropamine®, Mecoban®, Methar Tri-Kombi®*)
Benzoic acids	Dicamba (Banvel®, Banvel M®*, Barrel®*, Mecoban®, Methar Tri-Kombi®*)
Pyridine carboxylic acids (pyridines)	Aminopyralid (Hotshot®*,Grazon Extra®*), clopyralid (Lontrel®, Torpedo®*, Chipco Spearhead®*), fluroxypyr (Starane®, Hotshot®*), picloram (Tordon®, Tordon 242®*, Grazon®*, Grazon Extra®*), triclopyr (Garlon®, Grazon®*, Grazon Extra®*, Ultimate Brushweed®* Herbicide)

*This product contains more than one active constituent.

6.4.9 Specific guidelines for Group J herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	J	Herbicide

Moderate resistance risk.

There are isolated cases of weeds resistant to Group J in Australia. Two populations of serrated tussock and six populations of giant Parramatta grass are confirmed resistant to flupropanate.

To assist in delaying the onset of resistance, consider alternating with herbicides from other MOA.

The recommendations should be incorporated into an IWM program. Try to ensure surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups.

Table 10: *Active ingredients of Group J MOAs.*

Chemical family	Active constituent (first registered trade name)
Group J. Inhibitors of fat synthesis (not ACCase inhibitors)	
Chlorocarbonic acids	2,2-DPA (Dalapon®), flupropanate (Frenock®)
Thiocarbamates	EPTC (Eptam®), molinate (Ordram®), pebulate (Tillam®), prosulfocarb (Boxer® Gold*), thiobencarb (Saturn®), triallate (Avadex®), vernolate (Vernam®)
Phosphorodithioates	Bensuilde (Prefar®)
Benzofurans	Ethofumesate (Tramat®)

*This product contains more than one active constituent.

6.4.10 Specific guidelines for Group K herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	K	Herbicide

Moderate resistance risk.

Resistance to Group K herbicides is possible in Australia and may develop in broadacre situations.

Where possible, avoid the use of Group K herbicides on dense populations of ryegrass. Consider using alternative methods of weed control to reduce weed numbers before applying herbicides.

Rotate with herbicides from other modes of action. The recommendations should be incorporated into an IWM program. Try to ensure surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups.

Table 11: *Active ingredients for Group K MOAs.*

Chemical family	Active constituent (first registered trade name)
GROUP K. Inhibitors of cell division/inhibitors of very long chain fatty acids (VLCFA inhibitors).	
Acetamides	Napropamide (Devrinol®)
Chloroacetemides	Dimethenamid (Frontier®-P), metolachlor (Boxer® Gold*, Dual® Gold, Primextra® Gold*), propachlor (Ramrod®, Prothal®*)
Isoxazoline	Pyroxasulfone (Sakura®)

*This product contains more than one active constituent.

6.4.11 Specific guidelines for Group L herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	L	Herbicide

Moderate resistance risk.

Group L resistance exists in Australia in annual ryegrass, barley grass (two species), silver grass, cape weed, and square weed. Most instances have occurred in long-term lucerne stands treated regularly with a Group L herbicide, but Group L-resistant barley grass has also occurred in no-till situations.

The following factors are common to all cases of Group L resistance:

- A Group L herbicide is the major or only herbicide used.

- A Group L herbicide has been used for 12–15 years or more.
- There has been minimal or no soil disturbance following application.

The risk of resistance to Group L herbicides is higher in no-tillage broadacre cropping. Other situations of high resistance risk include irrigated clover pivots, orchards, vineyards, or pure lucerne stands where frequent applications of a Group L herbicide are made each season, cultivation is not used and there is reliance on a Group L herbicide alone for weed control.

Below are strategies to reduce the risk of Group L resistance developing in situations of high resistance risk.

No-tillage

Rotate Group L herbicides with other knockdown herbicides with a different mode of action.

Consider utilising the double-knock technique, with glyphosate sprayed first followed within 1–7 days by a paraquat application. A full label rate for the weed size targeted should be used for the paraquat application for resistance management. Consider occasional mechanical cultivation to aid weed control.

Lucerne

If using a Group L herbicide for winter cleaning, where possible include another MOA, e.g. diuron (Group C).

Use alternative MOA to selectively control grass and broadleaf weeds. Rotate Group L herbicides with other knockdown herbicides with a different MOA prior to sowing lucerne and prior to sowing future crops in that paddock.

Horticulture

Rotate Group L herbicides with other knockdown herbicides with a different MOA. Where possible, use residual herbicides (that are effective on the same weeds as the Group L herbicides) where applicable, either alone or in mixture with Group L herbicides. Where possible, use an alternative MOA to selectively control grass and broadleaf weeds. Consider using the double-knock technique, with glyphosate sprayed first followed within 1–7 days by a paraquat application. A full label rate for the weed size targeted should be used for the paraquat application for resistance management.

These recommendations should be incorporated into an IWM program. Try to ensure surviving weeds from any treatment do not set and shed viable seed. Always try to apply herbicides to the smallest weed density. Use integrated strategies, including rotation of MOA groups.

Table 12: *Active ingredients of Group L MOAs.*

Chemical family	Active constituent (first registered trade name)
Group L. Inhibitors of photosynthesis at photosystem I (PSI inhibitors)	
Bipyridyls	Diquat (Reglone®, Spray.Seed®*), paraquat (Gramoxone®, Spray.Seed®*, Alliance®*)

*This product contains more than one active constituent.

6.4.12 Specific guidelines for Group M herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	M	Herbicide

Moderate resistance risk.

Group M resistance occurs in Australia in annual ryegrass, awnless barnyard grass, fleabane, liverseed grass, and windmill grass.

Herbicide resistance to glyphosate was first discovered in annual ryegrass in Australia in 1996. Since then, several new cases of glyphosate resistance in annual ryegrass, awnless barnyard grass, fleabane, liverseed grass, and windmill grass have been confirmed.

The following factors are common to all cases of Group M resistance:

- A Group M herbicide is the major or only herbicide used.
- A Group M herbicide has been used for 12–15 years or more.
- There has been minimal or no soil disturbance following application.

Given the important role of glyphosate in Australian farming systems, the Australian agricultural industry has developed strategies for sustainable use of glyphosate.

For more information, refer to the Australian Glyphosate Sustainability Working Group website.

All cases of glyphosate resistant weeds confirmed to date share three common factors:

1. Intensive (year-to-year) use of glyphosate
2. Lack of rotation of other herbicide modes of action
3. Little or no tillage or cultivation following the application of glyphosate

Several cases of ryegrass resistance to glyphosate have occurred in horticultural and non-cropping situations (e.g. firebreaks, fence lines, driveways, irrigation ditches), with the balance occurring in no-till, broadacre cropping systems.

Given the demonstrated propensity of annual ryegrass to develop resistance to multiple herbicide classes, IWM principles should be incorporated wherever possible to minimise the risk of selecting for glyphosate-resistant ryegrass. Strategies may include the use of cultivation, the double-knock technique (using a full-cut cultivation OR the full label rate of a paraquat-based product (Group L) following the glyphosate (Group M) knockdown application), strategic herbicide rotation, grazing, and baling.

Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Always try to apply herbicides to the smallest weed density. Use the integrated strategies mentioned, including rotation of MOA groups.

Table 13: *Active ingredients of Group M MOAs.*

Chemical family	Active constituent (first registered trade name)
Group M. Inhibitors of EPSP synthase	
Glycines	Glyphosate (Roundup®, Trounce®*,Illico®*, Arsenal Xpress®*, Broadway®*)

*This product contains more than one active constituent.

6.4.13 Specific guidelines for Group Z herbicides

(Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'.)

Group	Z	Herbicide

Moderate resistance risk.

Group Z resistance exists in Australia in wild oats resistant to flamprop. Many of these flamprop-resistant wild oats also show cross-resistance to Group A herbicides. Resistance to endothal is confirmed in winter grass.

To assist in delaying the onset of resistance, rotate with herbicides from other MOAs. Consider using alternative methods of weed control to reduce weed numbers before applying herbicides. These may include summer crop rotations, delayed sowing to control wild oats with a knockdown herbicide, higher seeding rates and brown manuring to stop seed-set.

The recommendations should be incorporated into an IWM program. Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups.

Table 14: *Active ingredients of Group Z MOAs.*

Chemical family	Active constituent (first registered trade name)
Group Z. Herbicides with unknown and probably diverse sites of action	
Arylaminopropionic acids	Flamprop (Mataven L®)
Dicarboxylic acids	Endothal (Endothal®)
Organoarsenicals	DSMA (Methar®), MSMA (Daconate®)

*This product contains more than one active constituent.

Refer to the APVMA website to obtain a complete list of registered products from the PUBCRIS database.

6.4.14 Herbicide use according to growth stage

Table 15: *Herbicide use according to growth stage in chickpeas.*

Herbicide	Use	Growth stage
Group A		
butroxydim	Do not graze or cut for stockfeed within 14 days of application	Vegetative growth stage, prior to flowering, podding and seven weeks prior to harvest
butroxydim + fluazifop	Up to seven weeks before harvest	Vegetative growth stage, prior to flowering, podding and seven weeks prior to harvest
clethodim	Up to full flowering	Vegetative growth stage, prior to flowering, podding
fluazifop	Up to seven weeks before harvest	Vegetative growth stage, prior to flowering, podding and seven weeks prior to harvest
haloxyfop	Second branch through to flowering	Vegetative growth stage, prior to flowering, podding
propaquizafop	Up to 12 weeks before harvest	Vegetative growth stage
sethoxydim	Up to prior to flowering	Vegetative growth stage, prior to flowering, podding
tepraloxydim	Up to 12 weeks before harvest	Vegetative growth stage
Group B		
flumetsulam	Apply from four to six branches and no later than six weeks after emergence	Vegetative growth stage

Source: DPI NSW.

NOTE: For chickpeas, the window for application for selective grass control herbicides (Group As) is generally dictated by regulatory requirements to avoid residues in produce that exceed levels acceptable to various markets. Check the labels for individual herbicides but chickpea crop safety for most Group As is not influenced by growth stage up to at least flowering.

For up to date chemical Withholding Periods and other label information, see the APVMA search facility.

6.4.15 Getting the best results from herbicides

1. Control weeds as early as possible in the first six weeks after sowing.
2. Make sure that the crop and weeds are at the correct growth stage for the herbicide to be used.
3. Do not spray outside the recommended crop growth stages as damage may result.
4. Do not spray when the crop or weeds are under any form of stress such as drought, water logging, extreme cold, low soil fertility, disease or insect attack, or a previous herbicide.
5. Some herbicides should not be used when weeds are wet with rain or dew or if rain is likely to occur within three or four hours.
6. Do not spray in windy conditions (over 10–15 km/hour) as drift from herbicides can cause damage to non-target crops. Herbicide spray can also drift in very calm conditions, especially with air temperature inversions.
7. Use sufficient water to ensure a thorough, uniform coverage regardless of the method of application.
8. Use good quality water. Hard, alkaline or dirty water can reduce the effectiveness of some herbicides.
9. Maintain clean, well-cared for equipment. A poorly maintained spray unit will cost you money in breakdowns, blocked jets, poor results and perhaps worse, crop damage through misapplication.
10. After products such as Atlantis®, chlorsulfuron, Hussar® metsulfuron, or triasulfuron have been used in equipment, it is essential to clean that equipment thoroughly with chlorine before using other chemicals. After using Affinity®, Broadstrike®, or Eclipse® decontaminate with liquid alkali detergent.
11. Seek advice before spraying recently released pulse varieties. They may differ in their tolerance to herbicides. [17]

6.5 Summer fallow weed control

In a winter cropping system, the return on investment from managing weeds in summer fallow (i.e. the period between crops) is high. Economic benefits flow from both extra amounts of high value water and nitrogen, crop establishment benefits and reduced issues with weed vectored disease and insect pests.

Stopping weed growth in the fallow can lead to yield increases in the following crop via several pathways. These include:

- Increased plant available water
- A wider and more reliable sowing window
- Higher levels of plant available N
- Reduced levels of weed vectored diseases and nematodes
- Reduced levels of rust inoculum via interruption of the green bridge
- Reduced levels of diseases vectored by aphids that build in numbers on summer weeds, and
- Reduced weed physical impacts on crop establishment.

How farming country is managed in the months or years before sowing can be more important in lifting water use efficiency (WUE) than in-crop management. Of

17 GRDC (2008). Grain Legume Handbook – Weed control

MORE INFORMATION

Summer fallow weed management for growers in the Southern region

VIDEOS

3. Over The Fence South: Summer weed control saves moisture for winter crops

particularly high impact are strategies that increase soil capture and storage of fallow rainfall to improve crop reliability and yield.

Practices such as controlled traffic farming and long term no-till seek to change the very nature of soil structure to improve infiltration rates and improve plant access to stored water by removal of compaction zones.

Shorter term management decisions can have an equal or even greater impact on how much plant available water (PAW) is stored at sowing. These include decisions such as crop sequence/rotation that dictate the length of the fallow and amount of stubble cover, how effectively fallow weeds are managed, stubble management and decisions to till/not to till at critical times.

While many factors influence how much plant available water is stored in a fallow period, good weed management consistently has the greatest impact. [18]

6.6 Double knock strategies

Getting the best bang for your buck

The use of glyphosate as the first knock followed within one to seven days with the second knock application of paraquat or paraquat + diquat is increasing in southern Australia. A well-timed and executed double knock is a very useful first step to reducing weed pressure and keeping a lid on glyphosate resistant annual ryegrass. Building the double knock treatment into a whole-of-season weed management plan provides opportunities to get more 'bang for your buck'.

The first knock is to kill all plants still susceptible to glyphosate—applying a lower rate risks higher survival rates, increasing the pressure on the second knock products. The second knock of Spray.Seed® or paraquat is to kill plants that survived the glyphosate. Reducing the rate of the second knock risks survival of potentially glyphosate resistant individuals and damages the integrity of the double knock tactic. Remember that paraquat and Spray.Seed® are contact herbicides and require robust water rates to ensure adequate coverage, and allow for losses on stubble.

If the main weed problem is annual ryegrass then using paraquat on its own as the second knock is an appropriate choice. If there are also broadleaf weeds present, then the paraquat + diquat combination (e.g. Spray.Seed®) will be more effective overall. Mixing the glyphosate and paraquat together is both ineffective and not registered. Applying the two sprays between one and seven days apart is optimum timing.

If there is a mix of weeds present it can be useful to include a compatible herbicide 'spike' such as 2-4D low volatile ester, carfentrazone, or oxyflouren to enhance control of broadleaf weeds. Be very mindful of plant-back requirements of some herbicide 'spikes' before planting sensitive crops such as pulses and canola.

Don't rely on a pre-sowing double knock alone. Use pre-emergent herbicides, and focus on increasing the level of crop competition with narrow row spacing and varieties with vigorous early growth. Sow cereals at the optimal time to maximise competitiveness.

In weedy paddocks, consider the value of break crops such as pulses, canola, or hay as a way of incorporating other in-crop and non-chemical options to manage annual ryegrass, such as grass-selective post-emergent herbicides, crop-topping, desiccation, spraying under the swath or narrow windrow burning where appropriate. [19]

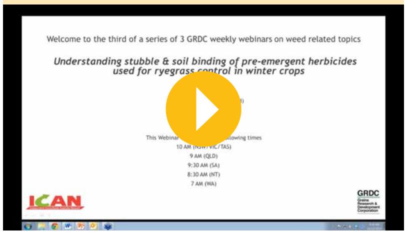
18 GRDC (2014). Summer fallow weed management. https://grdc.com.au/Resources/Publications/2014/05/Summer-fallow-weed-management

19 WeedSmart. 2015. How can I get the best best for my buck with a double knock? http://www.weedsmart.org.au/ask-an-expert/how-can-i-get-the-best-bang-for-my-buck-with-a-double-knock/

VIDEOS

4. [Pre-emergent herbicides – Pt 1 Solubility and Binding.]

5. [Webinar - Stubble & soil binding of pre-emergent herbicides for annual ryegrass control in winter crops.]



6.7 Pre-emergent herbicides

Pre-emergent herbicides are applied to the soil either before or directly after sowing and prior to weed emergence.

The pre-emergent herbicides alone will not adequately control large weed populations, and so they need to be used in conjunction with paddock selection and pre-seeding weed control.

Selection of the appropriate pre-emergent herbicide can only be made after assessing such factors as weed spectrum, soil type, farming system, and local experience. Refer to the complete product label for directions for use, application rates, weeds controlled, and conditions for best results.

Pre-sowing application is possible with some products and is often safer than post-sowing application because the sowing operation removes a certain amount of the herbicide from the crop row. Higher rates can often be used pre-sowing, but in both cases, the rate must be adjusted to soil type, as recommended on the product label.

6.7.1 Why use pre-emergent herbicides?

Pre-emergent herbicides are an essential part of a conservation farming system for a number of reasons:

- They can offer alternative modes of action to post-emergent herbicides.
- Many are very effective on hard-to-kill weeds such as annual ryegrass and barley grass.
- The current level of herbicide resistance to pre-emergent herbicides in NSW is very low.
- Pre-emergent herbicides control weeds early in crop life and potentially over multiple germinations, maximising crop yield potential.
- They suit a no till seeding system with knife points and press wheels and/or disc seeders.
- They can be cost effective. [20]
- There is also limited options for post emergent weed control in pulses. [21]

Whilst pre-emergent herbicides can be used in conservation farming systems, they must be used in conjunction with herbicide/crop rotation management plans and other non-chemical weed control techniques (Photo 4). These methods usually aim to minimise weed seed production and may include fallows, crop rotations including pastures and/or cutting hay, burning full paddocks or windrows, chaff carts, and weed seed destructors. [22]

Photo 4: *Trials have identified pre-emergent product combinations that provided significantly better control (right) than the district standard practice (left) for herbicide resistant annual ryegrass.*

Source: WeedSmart.

20 Haskins, B. NSW DPI. Using pre-emergent herbicides in conservation farming systems.

21 Stuchbery J. (2016) Personal communication.

22 Haskins, B. NSW DPI. Using pre-emergent herbicides in conservation farming systems.

VIDEOS

6. Webinar - Understanding pre-emergent herbicides.

6.7.2 Herbicide options

Chickpeas are late maturing (compared to other pulses), hence crop-topping to prevent ryegrass and other weed seed set is not possible, even in the earliest of maturing varieties (e.g. Genesis 079). Chickpeas are relatively slow to emerge with slow early growth during the colder winter months. As a consequence, they are poor competitors with weeds. Even moderate weed infestations can cause large yield losses and harvest problems.

The weed control strategy for growing a successful chickpea crop depends on substantially reducing the viable weed seed bank in the soil before the crop emerges. Control the majority of weeds before seeding, either by cultivation or with knockdown herbicides such as glyphosate or Spray Seed®.

A technique used with varying success by growers has been to sow chickpea and then use a knockdown herbicide tank mixed with a pre-emergent herbicide to control germinating weeds before the crop emerges. Chickpea crops may take up to 21 days to emerge under cool, drying soil conditions but under favourable warm, moist soil conditions plants may emerge after seven days. Done well, this can be an effective weed control option.

The pre-emergent herbicides will not adequately control large weed populations by themselves, and so they need to be used in conjunction with paddock selection and pre-seeding weed control. Incorporation by sowing (IBS) is generally considered safer on the crop than post-sowing pre-emergence with most herbicides used in modern no till sowing systems. Most of these products work best if thoroughly incorporated with soil either mechanically or by irrigation or rainfall. The aim of incorporation is to produce an even band of herbicide to intercept germinating weed seeds.

Simazine is the most widely used herbicide for broadleaf weed control, and can provide relatively cheap control of cruciferous weeds. Efficacy is very dependent on receiving rainfall (20–30 mm) within 2–3 weeks of application, and consequently weed control is often disappointing under drier conditions.

Balance® (isoxaflutole) is a systemic herbicide belonging to the relatively new class of isoxazole herbicides (Group H). Balance provides more consistent and reliable control of susceptible weeds for longer and across a broader range of seasonal conditions.

Terbyne is the newest triazine herbicide to be introduced in Australia and is registered for pre-emergent weed control in chickpeas, lupin, field peas, faba beans, lentils and triazine tolerant canola. Terbyne can be applied pre or post sowing.

Terbyne controls a wide range of broadleaf weeds, with some suppression of grasses, particularly if there is good soil moisture. Sufficient rainfall (20–30 mm) to wet the soil through the weed root zone is necessary within 2–3 weeks of application.

Spinnaker® (700 g/kg imazethapyr). For the pre-or post-emergence control of certain weeds in Centrosema (Cavalcade), chickpeas, faba beans, field peas, lucerne, mung beans, peanuts, serradella, soybeans and subterranean clover as per the directions for use table.

In chickpea crops sown on wide rows, there is increasing adoption of ‘directed sprays’ of Broadstrike, either alone or in tank-mixes with simazine. This largely avoids the problem of crop damage and improves weed control through the ability to safely add wetters or mineral oils to the spray mix.

Directed sprayers are most common in or around the cotton growing areas, as they enable relatively cheap grass and broadleaf weed control using glyphosate in-crop. While chickpeas do have a degree of tolerance to glyphosate during the vegetative stage, caution is still required as the lower branches arising from the main stem contribute a large proportion of the total chickpea yield. Upright varieties such as Amethyst and Jimbour are more suited to this technique than the more prostrate types and small chickpea plants are more susceptible to damage than older plants. [23]

23 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

Balance® (isoxaflutole) is a Group H herbicide and its use is specific to chickpeas for broadleaf weed control in broadacre cropping situations. It provides a weed control option unique to chickpeas and enables rotation of herbicide groups across the cropping sequence.

Pre-emergent herbicides in the high-rainfall zone

The seasonal conditions that unfold can have a significant effect on the efficacy of any product applied. Pre-emergent herbicide performance depends on herbicide characteristics, solubility, affinity to soil, modes of degradation and the weed spectrum targeted, germination characteristics, soil/sowing conditions, expected moisture/environmental conditions and the complex interaction of these factors. For example, some products are not well-suited to higher rainfall zones because multiple weed germinations are more likely and by later in the season the herbicide has dissipated or moved too far down the soil profile to have any effect on later germinations. [24]

An early series of trials were conducted to evaluate the selectivity of a range of herbicides in chickpeas (Table 16). Trifluralin had a narrow safety margin and rates in excess of 0.56 kg/ha were damaging. Pendimethalin produced similar damage at rate of 0.99 kg/ha and 1.98 kg/ha to trifluralin at rate of 0.84 kg/ha and 1.12 kg/ha. These herbicides reduced plant establishment by 15–38% with the greatest reduction at the higher rates. Where trifluralin-reduced chickpea stands to below 40 plants/m^2, a significant yield reduction of 14.5% occurred. The wild oat herbicide triallate, was safe on chickpeas at rate up to 2.24 kg/ha. When trifluralin was added to triallate, damage tended to be slightly worse than with trifluralin alone. [25]

Table 16: *Tolerance of chickpeas to pre-plant incorporation of herbicides.* [26]

Herbicide	Rate (kg a.i./ha)	No. of experiments (all harvested)	Significant reductions*	Average Yield (s.e.) (% site maximum)	Tolerance rating
Tri-allate	0.56-0.8	2	0	90.5 92.1)	T
	1.12-2.24	2	0	89.5 (9.2)	T
Pendimethalin	0.99	1	0	100	MT
	1.98	1	0	79	MS
Trifluralin	0.56	4	0	89.8 (5.0)	T-MT
	0.84	2	0	87.5 (4.9)	MT-MS
	1.12	2	1	85.5 (9.2)	MS
Trifluralin + Tri-allate	0.56+0.56	2	0	84.5 (12.0)	MT
Cyanazine+Trifluralin	2.0+0.40	1	0	89	T
Prodiamine	0.398	1	0	100	T
Unweeded control	-	4	1	86.3 (8.4)	
Handweeded control	-	3	0	96.3 (3.2)	-

* Number of experiments where yield < site maximum (P = 0.05).

6.7.3 Application

Most products work best if incorporated into soil, either mechanically or by irrigation or rainfall. The aim of incorporation is to produce an even band of herbicide to intercept germinating weed seeds. Some herbicide incorporation occurs when sowing is done with knife-points, provided sowing speed is adequate to throw soil

24 WeedSmart. Gearing up to use pre-emergent herbicides. http://www.weedsmart.org.au/webinars/setting-crops-up-for-success/

25 G Kay, M, McMillan. (1990). Pre and post emergent herbicides in chickpeas I. Crop tolerance. Proceedings of the 9th Australia Weed Conference.

26 G Kay, M, McMillan. (1990). Pre and post emergent herbicides in chickpeas I. Crop tolerance. Proceedings of the 9th Australia Weed Conference.

VIDEOS

7. GCTV16: Spray application Workshop.

into the inter-row without throwing into the adjacent seed furrow. Hence, these products are still compatible with the shift to minimum tillage and reduced-tillage farming practices. However, there may be insufficient soil throw with some low-disturbance, disc seeding systems. Typically, a follow-up, post-emergent grass weed herbicide is still required to provide the level of grass weed control desired by growers, particularly in the seed furrow.

6.7.4 Herbicide efficacy in retained stubble systems

The GRDC project 'Maintaining profitable farming systems with retained stubble—upper Eyre Peninsula' aims to improve farm profitability while retaining stubble in farming systems on upper Eyre Peninsula (EP). One of the barriers to retaining stubble is the perceived reduction in pre-emergent herbicide effectiveness in stubbles. This component of the project is testing whether various stubble management activities impact on herbicide efficacy.

Weed control in stubble-retained systems can be compromised when stubbles and organic residues intercept the herbicide and prevent it from reaching the desired target, or when the herbicide is tightly bound to the organic matter. Reduced herbicide efficacy in the presence of higher stubble loads is a particular issue for pre-emergent herbicides. Current farming practices have also changed weed behaviour with a shift in dormancy in barley grass genotypes now confirmed in many paddocks of the Minnipa Agricultural Centre.

To measure the efficacy of herbicides in different stubble management systems, two different stubble management strategies were implemented at harvest: traditional spread stubble and harvest windrows. The third stubble management strategy was total stubble removal by burning. The harvest windrows within the trial area were also burnt. Measurements taken were stubble load pre-seeding, soil moisture, plant emergence count, early and late grass weed count, medic growth score, grain yield, and grain quality.

Stubble treatments (averaged over all chemical treatments)

Early dry matter and grain yield were lower in the spread stubble system than the burnt stubble and burnt windrow systems and this may have been due to less moisture reaching the seedbed and also the tie up of nitrogen resulting in early nitrogen deficiency (Table 17). There may also have been some yellow leaf spot interactions.

Table 17: *Effect of cereal stubble management on crop establishment, dry matter and yield as well as weed and medic populations in 2015.*

	Establishment (plants/m²)	Early crop dry matter (t/ha)	Early in-crop barley grass 24 July (plants/m²)	Medic growth (0–3 rating)*	Late in-crop barley grass 26 Oct (plants/m²)	Yield (t/ha)
Burnt stubble	105	0.22	3.1	1.01	6.8	1.63
Spread stubble	93	0.19	1.8	0.78	4.8	1.55
Burnt windrows	97	0.22	6.7	0.94	10.3	1.69
LSD (P=0.05)	4	0.02	1.7	0.12	2.7	0.04

* Visual medic rating system where 0=no medic, 1=small suppressed medic, 2=small and large medic, 3=mostly large medic plants

Source: GRDC.

Chemical treatments

There were no impacts of stubble management on the performance of individual chemical treatments so results presented in this section are averaged over all three stubble management treatments.

Trifluralin and Diuron mixes caused some crop damage but the crop recovered better than expected and dry matter production of the crop was as good as in the untreated control by sampling time, this was probably due to less soil water movement of the chemicals. In a dry start, Boxer Gold® did not appear as effective on barley grass as ryegrass, but post-application gave some suppression activity on all grasses.

Despite high cereal stubble loads, completely removing stubble by burning did not improve the efficacy of any of the chemical packages tested in this trial. The generally low grass weed pressure observed in this trial, however, makes it difficult to draw any conclusive recommendations relating to the impact of stubble management based on these results alone.

When choosing the most appropriate pre-emergent herbicide for use in stubble retained systems, it is important to consider:

- the likely rainfall pattern and soil moisture conditions post application;
- the susceptibility of the crop to the herbicide;
- the position of the weed and crop seeds in the soil profile;
- the mobility of the herbicide in soil water;
- the persistence of the herbicide activity relative to the germination pattern of the target weeds;
- specific tillage/seeding system and level of soil disturbance, and;
- long-term objectives of the weed management program. [27]

MORE INFORMATION

APVMA

Using pre-emergent herbicides in conservation farming

Pre-emergent herbicides Factsheet.

6.8 Post-plant pre-emergent herbicides

When a pre-emergent herbicide is applied after sowing (but before crop emergence) to the seedbed (Table 18).

These herbicides are primarily absorbed through the roots, but there may also be some foliar absorption (e.g. Terbyne®). When applied to soil, best control is achieved when the soil is flat and relatively free of clods and trash. Sufficient rainfall (20–30 mm) to wet the soil through the weed root-zone is necessary within 2–3 weeks of application. If applied pre-sowing and sown with minimal disturbance, incorporation will essentially be by rainfall after application. Weed control in the sowing row may be less effective because a certain amount of herbicide will be removed from the crop row.

The absence of cost-effective and safe post-emergent herbicides effectively limits broadleaf weed control options in chickpeas to a small number of pre-emergent herbicides. Most of these chemicals are very dependent on rainfall soon after application, and as a consequence often result in inconsistent or partial weed control under drier conditions. [28]

An early series of trials were conducted to evaluate the selectivity of a range of herbicides in chickpeas (Table 18). The herbicides which performed best under post-plant pattern were all triazines. In one experiment, mixtures with simazine were more dmaaging than herbicides applied alone at comparable total rate of the active triazine. Chickpeas have consistently shown a haigh tolerane to registered herbicide cyanazine at rates up to 3.0 kg/ha and to prometryn at rates of 2.0 kg/ha or less. Damage symptoms were temporary and did not affect yields. Metribuzin was usually safe at a rate of 0.21 kg/ha but in one weedfree experiment a significant yield reduction occurred at this rate.

Table 18: *Tolerance of chickpeas to post-sowing, pre-emergence herbicides.* [29]

27 Cook A, Bates A, Shepperd W, Richter I. GRDC Update Papers (2016). Herbicide efficacy in retained stubble systems. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/08/Herbicide-efficact-in-retained-stubble-systems

28 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

29 G Kay, M, McMillan. (1990). Pre and post emergent herbicides in chickpeas I. Crop tolerance. Proceedings of the 9th Australia Weed Conference.

Herbicide	Rate (kg a.i./ha)	No. of experiments (all harvested)	Significant reductions*	Average Yield (s.e) (% site maximum)	Tolerance rating
Acifluorfen	0.224-0.896	7 (7)	0	93.8 (5.4)	T-MT
Atrazine	1.0	3 (3)	2	49.0 (40.0)	T
Cynazine	1.5	9 (8)	0	4.9 (4.9)	T
	2.0	5 (4)	0	88.0 (1.6)	T-MT
	3.0	1 (1)	0	98	T-MT
Dimethazone	0.9	1 (1)	1	59	HS
Imazaquin	0.3	1 (1)	1	41	HS
Imazethapyr	0.05-0.07	2 (2)	2	77.5 (3.5)	S
Linuron	1.5	1 (1)	0	92	MT
Methabenzthiazuron	1.75	2 (1)	0	94	T-MT
Metribuzin	0.21	10 (8)	2	88.9 (10.6)	T-MT
	0.28	3 (3)	3	61.0 (26.2)	MT-MS
	0.42	1 (1)	1	70	MS
Prometryn	0.75	3 (3)	0	95.3 (4.0)	T
	1.5	9 (8)	1	92.8 (5.8)	T
	2.0	2 (2)	0	94.5 (7.8)	T-MT
	3.0	1 (1)	0	87	MS
Simazine	0.75	6 (5)	1	87.8 (6.3)	T
	1.0	3 (3)	1	88.7 (1.2)	T
	1.25	1 (1)	1	85	T-MT
	1.5	6 (5)	2	87.0 (8.5)	T-MT
	2.5	1 (1)	1	55	MS
Terbutryn	2.0	2 (2)	1	78 (2.8)	T-MT
Cyanazine + metolachlor	2.0 + 1.44	1 (1)	0	82	T
Cyanazine + simazine	0.75-1.0+0.75	6 (5)	1	89.4 (8.7)	T-MT
Metribuzin + simazine	0.105-0.14+0.75	6 (5)	0	91.6 (6.2)	MT
Prometryn + simazine	0.75+0.75	6 (5)	1	91 (6.5)	T-MT
	1.5+0.75	3 (3)	0	89 (4.2)	MT
Unweeded control	-	13 (12)	5	76.9 (23.0)	-
Handweeded control	-	10 (9)	0	94.6 (4.7)	-

* Number of experiments where yield < site maximum (P = 0.05).

Results with simazine suggest that chickpeas were tolerant to rates less than 1 kg/ha (of active ingredient) but significant yield reductions due to poor weed control occurred at these rates in two experiments. Some variation was found on different soil types. In one trial on grey clay soils chickpea yield was reduced by 0.4 t/ha in the simazine 1.25 kg/ha treatment but on other soil types, no yield reduction occurred at 1.5 kg/ha. Damage symptoms developed slowly and usually increased as the season progressed. Yield losses from simazine were greater than would be expected from visual damage ratings. [30]

30 G Kay, M, McMillan. (1990). Pre and post emergent herbicides in chickpeas I. Crop tolerance. Proceedings of the 9th Australia Weed Conference.

IN FOCUS

Effect of row spacing, nitrogen and weed control on crop and weed in a wheat – lupin or wheat – chickpea rotation

Key messages

- Despite a very dry season in 2012, dimethenamid (e.g. Outlook®) herbicide in a lupin or chickpea crop was more effective on annual ryegrass than simazine in the two long-term rotational trials at Cunderdin and Merredin. This has resulted in an increase in grain yield of lupin crop in Outlook® treatment at Cunderdin.
- Sakura® reduced annual ryegrass head numbers more effectively than trifluralin at N_25 and flexi N50 compared to N50 at Merredin.
- Grain yields of both crops at Merredin were very poor. Despite poor grain yields of crops at Merredin, yields of both crops were greater at 44 cm row spacing than at 22 cm row spacing.

In 2012, rotation trials of three years duration were initiated at Cunderdin (wheat–lupin) and at Merredin (wheat– chickpea) to examine the effect of crop row spacing, herbicides and applied nitrogen (in wheat only) on crops and weeds.

Conclusions

Rainfall was extremely low at both sites in the 2012 season leading to very poor crop growth. Dimethenamid (e.g. Outlook®) herbicide was more effective on annual ryegrass than simazine in lupin and chickpea crops resulting in greater lupin grain yield. Even though grain yields of crops were very low, yields of both crops at Merredin were greater at 44 cm row spacing than at 22 cm row spacing. These results showed the benefit of wide row spacing in a dry season like 2012 in low rainfall areas. However, under high weed competition at Cunderdin, narrow row spacing appeared more productive with Outlook® herbicide than wide row spacing. [31]

Chickpea post-emergent herbicide trials 2014

Take home messages

- Factor® (butroxydim) was not effective as a knockdown for wild oats in chickpeas.
- Mixtures of Verdict® (haloxyfop) plus Status® (clethodim) or 500 mL/ha of Status® proved the most effective brews for knockdown control of wild oats.
- Clethodim (as Status®) benefited from the addition of Liase® even when rain water was used as the carrier. Be sure to follow label conditions.
- In reviews of the 2013 winter season agronomists and farmers had raised managing resistant populations of wild oats as a major issue for the Northern region and an emerging issue for the Southern region. Wild oats are a key weed of winter crops throughout the region and for the past 30 years growers and agronomists have relied on Group A herbicides for control.

Haloxyfop, a "fop" herbicide, is perhaps the most widely used herbicide in the Northern region for knockdown of wild oats in chickpeas and other pulse crops, however resistance to this herbicide is becoming increasingly frequent. This could

31 A Hashem, W Vance, R Brennan, R Bell. (2013). DAFWA 2013 Crop Updates. Effect of row spacing, nitrogen and weed control on crop and weed in a wheat – lupin or wheat – chickpea rotation.

eventually threaten Southern crops as well. Many agronomists, where they have concerns about the Group A resistance status of wild oats in a paddock, will mix haloxyfop (e.g. Verdict 520) with a “dim” herbicide (most commonly clethodim), other agronomists might use clethodim alone.

Butroxydim (e.g. Factor) is another “dim” group A that although registered for wild oat control in many broadleaf crops has not been widely used in NSW.

MORE INFORMATION

Wide rows and stubble management.

6.9 In-crop herbicides: knock downs and residuals

Chickpeas can be grown in wider rows in a stubble system that allows inter-row herbicide application with shielded sprayers.

Problem weeds or situations that require special attention include:

- Group A (‘dims’ and ‘fops’) resistant wild oats (and other grass species)
- late germinations of weeds (e.g. ryegrass, brome grass) that would normally be prevented from setting seed in other pulses through croptopping
- snail medic, which can escape Balance®
- hoary cress, soursob, tares, wild vetch, bedstraw, bifora, muskweed, wild radish and volunteer pulses[32]

Broadstrike® usually causes some transient crop yellowing and can cause reddish discoloration and height suppression. Flowering may be delayed (Photo 5), resulting in yield suppression.

Photo 5: *To control turnip weed, a single boom width of Broadstrike® was applied. Flowering and maturity of treated chickpeas (left) was delayed significantly, so they are still green compared with the untreated chickpeas that have matured (right).*

Photo: G. Cumming, Pulse Australia.

Broadstrike® is used mainly in salvage situations (as a last resort), and even then should be applied only under good growing conditions. Photo 6 depicts effective use of Broadstrike® against turnip weed adjacent to a chickpea crop.

With the shift into row-crop chickpeas, some growers are successfully using Broadstrike® as a directed spray into the inter-row area. This keeps a large proportion of the herbicide off the chickpea foliage and minimises crop damage.

32 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

Photo 6: *The same single boom width of Broadstrike® applied along the chickpea crop edge (centre) alongside the unsown, weedy headland (right) and untreated crop (far left). Broadstrike® did an excellent job on the turnip weed (centre and unsown front) compared with the untreated headland (right).*

Photo: G. Cumming, Pulse Australia.

6.9.1 Directed sprays

Though row-cropping chickpeas on wide rows in the Southern region is not commonly practiced, it provides an opportunity for the use of 'directed sprays' of Broadstrike®, either alone or in tank-mixes with simazine. This largely avoids crop damage and improves weed control through the ability to add wetters or mineral oils safely to the spray mix.

6.9.2 Shielded sprayers

Although chickpeas do have a degree of tolerance to glyphosate during the vegetative stage, caution is still required as the lower branches arising from the main stem make a large contribution to the total chickpea yield. Issues that need to be considered include:

- selection and operation of spray shields (speed, nozzle type, etc.)
- height of the crop (small chickpea plants are more susceptible)
- variety (upright types are more suited to this technique than the more prostrate types)

6.9.3 Brome and barley grass management in cropping systems of southern Australia

Take-home messages:

- Increasing incidence of brome and barley grass in cropping paddocks in southern Australia is likely to be associated with selection of more dormant biotypes by weed management practices used by the growers.
- At present brome grass management in cereals is heavily reliant on group B herbicides, especially the Clearfield™ technology. Delaying onset of resistance to these herbicides would require identification of effective alternative herbicides.
- Field trials undertaken over four years have investigated various pre-emergence herbicides for brome grass control in wheat. Even though Sakura® (pyroxasulfone) appears to be the most active pre-emergence herbicide against brome grass, it lacks consistency required for long-term population management of brome grass.

- Field trials over four years confirmed consistently high efficacy of Sakura® against barley grass, especially under situations with good soil moisture.
- Barley grass management is now being complicated by evolution of group A resistance in this weed species. However, there appear to be several effective alternatives (e.g. Sakura® and Raptor®) that could be used for barley grass control in broadleaf crops.

Feedback from growers and consultants in southern Australia has clearly shown increasing spread of brome and barley grass.

Brome grass management in broadleaf crops is heavily reliant on the use of group A herbicides. However, there are more than 30 cases of confirmed resistance in brome grass to group A herbicides.

Herbicide rotation has been widely recognised as being important to delay onset of resistance to herbicides. In order to implement herbicide rotations to delay group B resistance in brome grass, it is important to identify alternative modes of action.

Field studies have been undertaken over four years to investigate the performance of alternative modes of action to control brome grass. Sakura® and its combination with other herbicides were investigated for the control of brome grass. In some of these field trials, Sakura® alone provided excellent control (>90%) of brome grass (Figure 1). However, at the other trial sites, the level of weed control was quite disappointing (25%). At this stage, underlying reasons for this large variability in the performance of Sakura® on brome grass are unclear. Use of split application of Sakura® was equally variable as its single pre-sowing application. Addition of Avadex® (triallate) to Sakura® improved brome grass control relative to Sakura® alone in 2012 but the level of weed control obtained at Balaklava was inadequate (<60%). However, this treatment appears to be worthy of further research. In most situations, addition of trifluralin to Sakura® did not significantly improve brome grass control. In summary, it could be argued that none of the currently available pre-emergence herbicides have the required stability in efficacy to become viable alternatives to post-emergence group A or imidazolinone herbicides.

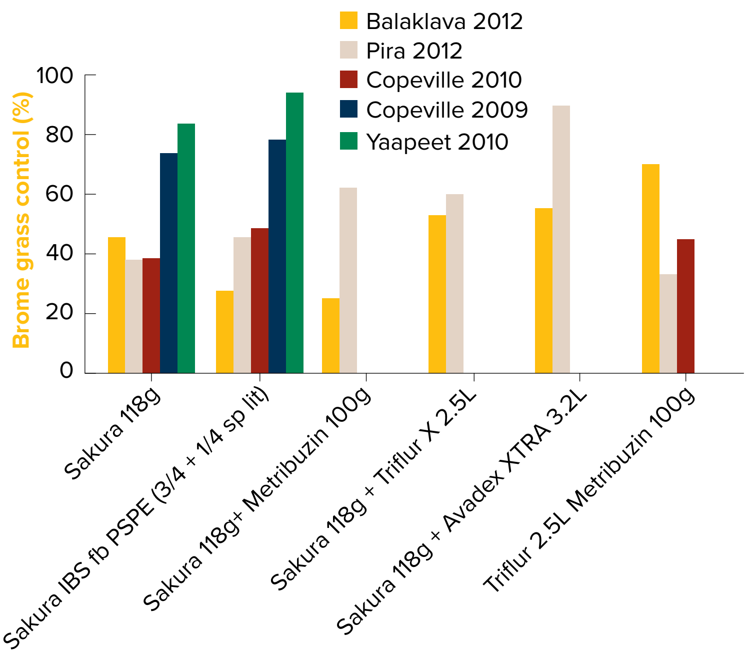


Figure 1: *Effect of different pre-emergence herbicides on the control of brome grass in field trials. It should be noted that rates of Triflur X and Avadex® were lower in trials undertaken prior to 2012. Weed control is expressed as reduction in brome grass plant density.*

Source: GRDC.

Barley grass management

Many growers have reported an increasing incidence of barley grass in their crops. Weed management practices used in cropping systems have selected for increased seed dormancy, which is likely to contribute to greater abundance of this weed species in field crops.

Release of pyroxasulfone (Sakura®) in Australia has been an important development in the management of barley grass. In many field trials undertaken on the Eyre Peninsula over four years, Sakura® consistently provided effective control of barley grass (Figure 2). Unfortunately, many farmers are still using cheaper but inferior herbicide options for barley grass, which can lead to large build-up in weed infestations.

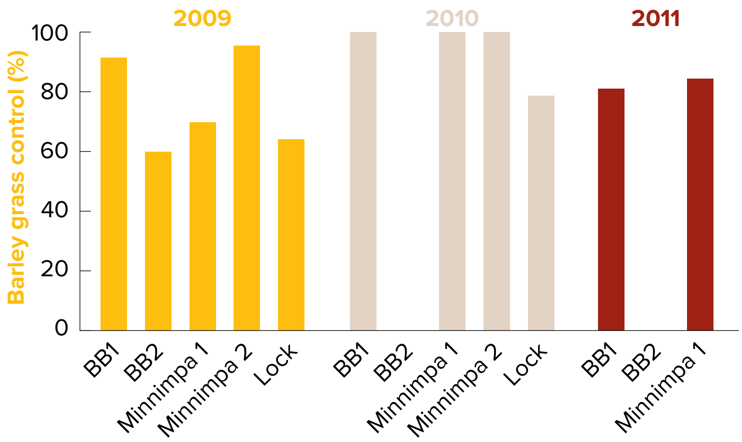


Figure 2: *Effect of Sakura® at the recommended rate (118 g/ha) on barley grass control in wheat at trial sites on the Eyre Peninsula. Weed control is expressed as reduction in barley grass seed production. BB = Buckleboo; 1 and 2 represent time of sowing.*

Source: GRDC.

Presence of high levels of resistance to group A herbicides is a major concern for weed management in pulse crops. In order to investigate the performance of alternative herbicides on group A resistant barley grass, a field trial was conducted at Baroota in 2012. Sakura®, Raptor® (imazamox), and an experimental compound provided excellent control of barley grass, which was reflected in significant increases in grain yield of field peas (Table 19). Outlook® (dimethenamid) appeared to be relatively ineffective early in the season but its performance improved with time and it may have a useful role in field peas. [33]

33 GRDC Update Papers. 2013. Brome and Barley grass management in cropping systems of southern Australia. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Brome-and-barley-grass-management-in-cropping-systems-of-southern-Australia

Table 19: *Effect of different herbicide treatments on grain yield of field peas and reduction in group A resistant barley grass seed production at Baroota (SA) in 2012.*

Treatments	Seed set reduction (%)	Field pea yield (t/ha)
Sakura® @ 118 g/ha IBS	99	2.29
Boxer Gold® @ 2.5 L/ha IBS	74	1.41
Outlook® @ 1 L/ha IBS	93	2.14
Raptor® @ 45 g/ha + BS1000 0.2% PE	100	2.08
Trifluralin @ 2.0 L/ha + Avadex® Xtra @ 2.0 L/ha	71	1.32
Metribuzin @ 200 g/ha PSPE	46	0.82
Propyzamide 500 g a.i./ha	100	2.29
Diuron 900@ 1 kg/ha + Trifluralin @ 2.0 L/ha IBS	78	1.58
Trifluralin 2.0 L/ha IBS	68	1.19
Control	-	0.82
LSD (P=0.05)		0.33

Source: GRDC.

6.10 Conditions for spraying

All grass herbicides labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions (Photo 7). Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, likely resulting in incomplete kill or only suppression of weeds:

- moisture stress (and drought)
- waterlogging
- high temperature–low humidity conditions
- extreme cold or frosts
- nutrient deficiency, especially effects of low nitrogen
- use of pre-emergent herbicides that affect growth and root development; i.e. simazine, Balance®, trifluralin, and Stomp®
- excessively heavy dews resulting in poor spray retentions on grass leaves

Photo 7: *Boom spray on crop.*

Photo: Brad Collis, Source: GRDC.

Ensure that grass weeds have fully recovered before applying grass herbicides.

Group A herbicides can occasionally cause leaf spotting in chickpeas (Photo 8). This is usually associated with either frost or high temperatures occurring soon after spray application. [34]

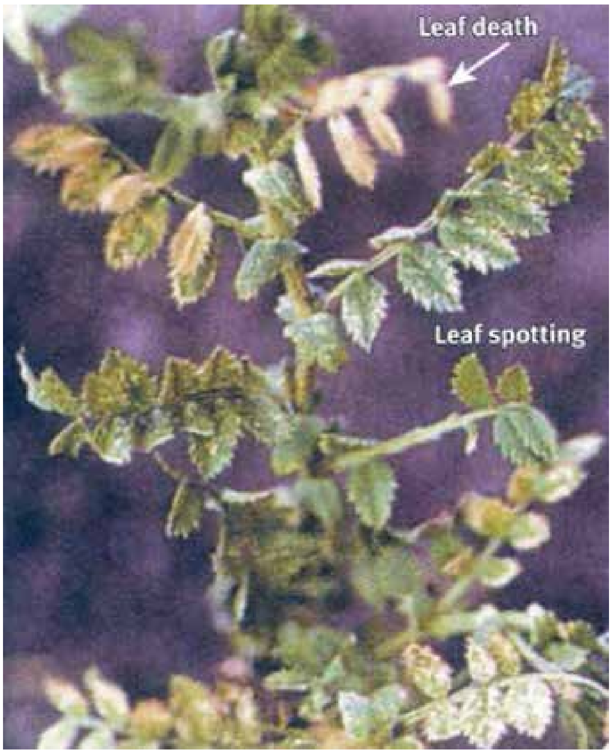
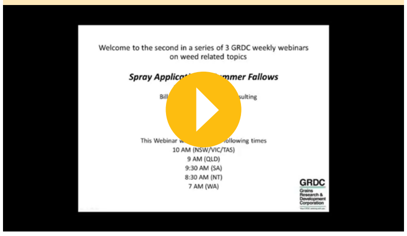


Photo 8: *Group A grass selective herbicide injury.*

Photo: T. Bretag.

VIDEOS

8. Advances in weed management – Webinar 2 – Spray application in summer fallows.



34 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

MORE INFORMATION

Cultivar herbicide tolerance trial protocols

6.11 Herbicide tolerance ratings, NVT

Within many broad acre crop species, cultivars have been found to vary in sensitivity to commonly used herbicides and tank mixes, thereby resulting in potential grain yield loss, and hence reduced farm profit. With funding from GRDC and State Government Agencies across Australia, a series of cultivar by herbicide tolerance trials are conducted annually. The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species including chickpeas, lupins, peas, lentils and faba beans. The intention is to provide data from at least two years of testing at the time of wide scale commercial propagation of a new cultivar. [35] See the results of the most recent trials below.

Pulse variety response to herbicides in Victoria

Pulse variety response to herbicides in South Australia

6.11.1 Developing improved herbicide tolerance in pulse crops

Herbicides are the main method of weed control in broadacre intensive farming systems and the development of herbicide tolerance traits in pulse crops has been identified as a major breeding priority. The recent release and rapid adoption of the first herbicide tolerant lentil XT varieties demonstrates the likely demand for these traits in other pulse crops, particularly faba beans where no in-crop broadleaf weed control options are currently available. Additionally, the development of multiple herbicide tolerances, particularly for different modes of action, is important to ensure robust and sustainable weed control options into the future. This project explored a number of different strategies to develop lines with improved tolerance to key herbicides in chickpeas, faba beans, and lentils.

Mutagenesis methods have been successfully used in the development of novel herbicide tolerance traits in a number of commercialized crops. In this project, mutagenized populations of lentils, faba beans, and chickpeas were screened for tolerance to a range of herbicides, and selections with high levels of putative tolerance were identified in each crop (Table 20). Details of the herbicide tolerant traits for each crop are described below.

Table 20: *Summary of herbicide tolerant germplasm developed through mutagenesis methods.*

	Chickpea
Mutated cultivar	PBA HatTrick⍉
Herbicide	clopyralid
Year/s screened	2014
Population size screened	Five million M_2 seeds
Field selections collected	67 M_2 plants
Lines progressed with herbicide tolerance trait	50 lines
Level of improved tolerance developed	High
Current status of validation	Dose response experiments 2016

Source: GRDC.

Fifty chickpea lines were confirmed to have improved tolerance to clopyralid in progeny screen experiments, with preliminary experiments indicating a high level of tolerance in these lines (Photo 9).

35 Ramsey C, Wheeler R, Churchett J, Walker S, Lockley P, Dhammu H, Garlinge J. (2010). Cultivar herbicide tolerance trial protocols. http://www.nvtonline.com.au/wp-content/uploads/2013/02/Herbicide-Tolerance-Protocols.pdf

All lines were bulked up during the 2015 season to multiply seed for future studies including dose experiments in 2016, and PBA Chickpea has started opportunistically incorporating lines with this trait into the breeding program.

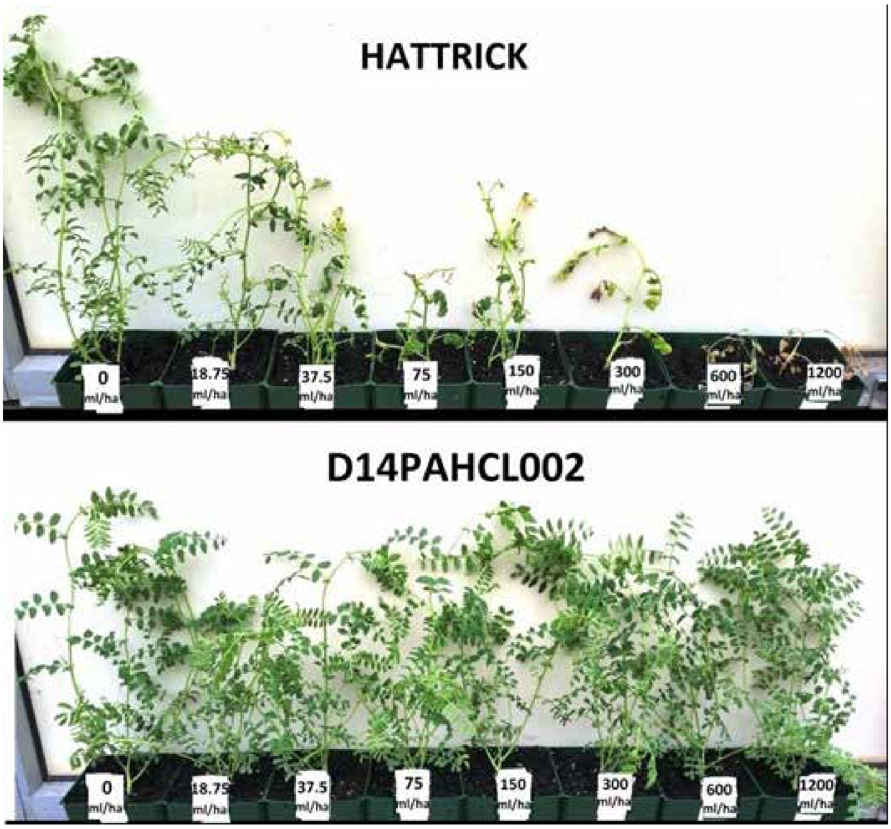


Photo 9: *Photo from a preliminary clopyralid dose response showing improved tolerance levels of a chickpea selection D14PAHCL002 compared to control cultivar PBA HatTrick⊕.*

Source: GRDC.

Summary and future work

The development of lines with low levels of herbicide tolerance from existing germplasm as well as high levels of improved tolerance from novel germplasm will help to improve grower confidence, expand weed control options and reduce the rotational limitations of pulse crops. All traits are being progressed in PBA breeding programs and new traits will continue to be evaluated in dose response and field trials as seed becomes available. Molecular markers will continue to be developed for all traits wherever possible; however, this may be difficult in selections from existing germplasm with low levels of tolerance as they are likely to be complex (multi-gene) traits. Selections from novel germplasm can potentially carry deleterious genes and further work may be required to understand any limitations associated with these new traits. Further characterisation of these traits, such as evaluation of tolerance levels to other herbicides with the same mode of action, is also required to allow the best registration opportunities to be pursued. Additionally, future work in developing tolerance to different herbicides with different modes of action is also necessary in lentils and faba beans, and could also be extended to other crops such as field peas, to ensure robust and sustainable weed control options into the future. [36]

36 GRDC Update Papers (2016). Developing improved herbicide tolerance in pulse crops. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Developing-improved-herbicide-tolerance-in-pulse-crops

6.11.2 New opportunities for pulses in the Mallee

Take home messages

- Weed management options in pulses continues to improve through incorporation of multiple techniques in crop management including: in-crop weed control with herbicides, plant traits for enhanced weed competitiveness and reducing weed seed set. A particular highlight recently has been the release of the XT lentil varieties which have improved tolerance to Group B herbicides.
- Where Group B residues are not an issue or requirements for in crop application of imazethapyr are not required, careful consideration should be made to the yield and other trait benefits of several other conventional lentils which may prove more profitable.

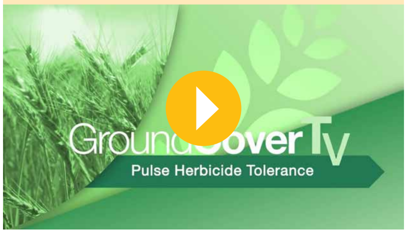
The opportunities for pulses in the Mallee continue to expand as we see improvements in farming systems and genetic advancements in traits that confer improved adaptation to Mallee conditions. Several PBA chickpea, field pea, lupin, faba bean and lentil lines already display improved adaptation to the low-medium rainfall zone (LRZ) having been developed in the run of drought years, particularly through the late 2000s. Current advanced PBA breeding lines will have even greater adaptation to the LRZ, encompassing traits such as novel tolerance to herbicides, different flowering times and durations, boron and salt tolerance and high relative yield under drought conditions. These traits, combined with optimised agronomic management in the specific environments, will enable further expansion of pulses as a profitable and successful component of a farming system in the Mallee.

Bright future for weed control in pulses

Building on the success of the lentil research, the SARDI pre-breeding project has developed Group B tolerant faba beans and Group C tolerant lentil germplasm. Agronomic field trials in SA in 2014 confirmed faba bean lines with tolerance to a range of Imi chemistries and early generation PBA yield trials have identified lines with good adaptation to southern Australia. Preliminary field validation trials also confirmed a very high level of metribuzin tolerance (10–20 times) in lentil germplasm. This material has now been 'crossed' with the Group B tolerant lines with the aim of developing dual herbicide tolerant (Group B+C) varieties. The project is now expanding into the development of novel herbicide tolerance in both Kabuli and Desi chickpea. [37]

VIDEOS

9. GCTV16: Pulse Herbicide Tolerance.



6.12 Monitoring

Monitoring of weed populations before and after any spraying is an important part of management.

- Keep accurate records.
- Monitor weed populations and record results of herbicide used.
- If herbicide resistance is suspected, prevent weed seed-set.
- If a herbicide does not work, find out why.
- Check that weed survival is not due to spraying error.
- Conduct your own paddock tests to confirm herbicide failure and determine which herbicides remain effective.
- Obtain a herbicide-resistance test on seed from suspected plants, testing for resistance to other herbicide (MOA) groups.
- Do not introduce or spread resistant weeds in contaminated grain or hay.

Regular monitoring is required to assess the effectiveness of weed management and the expected situation following weed removal or suppression. Without monitoring, we cannot assess the effectiveness of a management program or determine how it might be modified for improved results. Effective weed management begins with

37 GRDC Update Papers (2015). New opportunities for pulses in the Mallee. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/New-opportunities-for-pulses-in-the-Mallee

monitoring weeds to assess current or potential threats to crop production, and to determine best methods and timing for control measures.

Regular monitoring and recording details of each paddock allows the grower to:

- spot critical stages of crop and weed development for timely cultivation or other intervention;
- identify the weed flora (species composition), which helps to determine best short- and long-term management strategies; and
- detect new invasive or aggressive weed species while the infestation is still localized and able to be eradicated.

Watch for critical aspects of the weed-crop interaction, such as:

- weed seed germination and seedling emergence
- weed growth sufficient to affect crops if left unchecked
- weed density, height, and cover relative to crop height, cover, and stage of growth
- weed impacts on crops, including harbouring pests, pathogens, or beneficial organisms; or modifying microclimate, air circulation, or soil conditions; as well as direct competition for light, nutrients, and moisture
- flowering, seed-set, or vegetative reproduction in weeds
- efficacy of cultivations and other weed management practices

Information gathered through regular and timely field monitoring helps growers to select the best tools and timing for weed-control tactics. Missing vital cues in weed and crop development can lead to costly efforts to rescue a crop, efforts that may not be fully effective. Good paddock scouting can help the grower to obtain the most effective weed control for the least fuel use, labour cost, chemical application, crop damage, and soil disturbance.

6.12.1 Tips for monitoring

To scout weeds, walk slowly through the paddock, examining any vegetation that was not planted. In larger paddocks, walk back and forth in a zigzag pattern to view all parts of the paddock, noting areas of particularly high or low weed infestation. Identify weeds with the help of a good weed guide or identification key for your region, and note the weed species that are most prominent or abundant. Observe how each major weed is distributed through the paddock. Are the weeds randomly scattered, clumped or concentrated in one part of the paddock?

Keep records in a field notebook. Prepare a page for each paddock or crop sown, and take simple notes of weed observations each time the paddock is monitored. Over time, your notes become a timeline of changes in the weed flora over the seasons and in response to crop rotations, cover crops, cultivations and other weed control practices. Many growers already maintain separate records for each paddock; weed observations (species, numbers, distribution, size) can be included with these.

When to scout, and what to look for in a new paddock or farm

When purchasing farmland, it is important to look at the weeds. Presence of highly aggressive or hard-to-kill weeds, intense weed pressure, stressed and nutrient-deficient weeds, or a weed flora indicative of low or unbalanced soil fertility, pH or salt may foretell problems that should be considered when deciding whether to buy or rent, or how much to offer.

During your first year or two on a new farm or paddock, study the weeds carefully throughout the season, and be sure to get correct identification of the 5–10 most common weeds.

Note the weeds that emerge, grow or reproduce at different times of the annual cropping cycle:

- over winter

- after primary tillage and during seedbed preparation
- after crop planting
- during crop growth and maturation
- after harvest
- over summer or during cover crop emergence and establishment

Questions to ask include:

- What are the main weed species present at different times of year?
- When does each weed species emerge, flower, and set seed?
- What paddocks or areas have the worst weed pressure? The least?

6.13 Potential herbicide damage effect

Pulse crops can be severely damaged by some herbicides whether as residues in soil, contaminants in spray equipment, spray drift onto the crop or by incorrect use of the herbicide.

Leaching

Some soil active herbicides used for weed control in pulses can damage crops where conditions favour greater activity and leaching.

Herbicides move more readily in soils with:

- low organic matter
- more sand, silt, or gravel.

Herbicide movement is much less in soils with higher organic matter and higher clay contents. Damage from leaching is also greater where herbicides are applied to dry, cloddy soils than to soils which have been rolled and which are moist on top from recent rainfall. The pH of a soil can also strongly influence the persistence of herbicides. Many labels have warnings about high pH (≥8.0) and the need to reduce application rates to avoid crop damage. Heavy rainfall following application may cause crop damage. This will be worse if the crop has been sown shallow (less than 3–5 cm), where there is light soil and where the soil surface is ridged. The soil surface should not be ridged as this can lead to herbicides being washed down and concentrated in the crop row. [38]

Whilst trifluralin is relatively immobile in the soil, Boxer Gold® may move from the point of placement, particularly in sandy soils prone to leaching. Thus care must be taken in soils with a higher leaching potential and where previous history has shown potential for damage from herbicides with a higher leaching index such as Dual Gold®, metribuzin and the triazine herbicides. [39]

Based on Table 21, Metribuzin leaches at almost three times the rate of simazine and seven times the rate of diuron. The relative tolerance of the crop type and variety will also affect crop damage from these herbicides. For example, lupins are more tolerant to simazine than are the other pulses. For more specific details on soil active herbicides and the risk of crop damage in your cropping situation seek advice from an experienced agronomist.

Herbicide residues can last for several years, especially in more alkaline soils and where there is little summer rainfall. The pulses emerge and grow normally for a few weeks and then start to show signs of stress. Leaves become off-colour, roots may be clubbed, plants stop growing, and eventually die. Refer to the labels for recommendations on plant-back periods for pulses following use of any herbicides.

38 GRDC (2008). Grain Legume Handbook – Weed control.

39 Douglas A. (2008). Weeds Update, Western Australia.

Contamination of spray equipment

Traces of sulfonylurea herbicides (such as chlorsulfuron, metsulfuron, or triasulfuron) in spray equipment can cause severe damage to legumes when activated by some of the grass control herbicides (Photo 10). The risk of residue damage is greater in the presence of grass-selective herbicides. Always clean spray tanks and lines with chlorine, according to recommendations, after using sulfonylurea herbicides and before using these grass control herbicides. Traces of Affinity® (and many registered herbicides) can also damage pulse crops.

Decontaminate with alkali detergent.

Photo 10: *Hygiene between spraying operations is essential. After using herbicide make sure the boom spray is cleaned out with chlorine before starting on grass control in legumes. The effect, as shown above, is dramatic.*

Source: GRDC.

Spray Drift

Pulse crops can be severely damaged by some herbicide sprays, such as 2,4-D ester, drifting into the crop (Photo 11). This can happen when these sprays are applied nearby in very windy or still conditions, especially where there is an inversion layer of air on a cool morning. When using these herbicides spray when there is some wind—to mix the spray with the crop. Do not use excessively high spray pressure as this will produce too fine a spray, which is more likely to drift onto a neighbouring pulse crop. [40]

40 GRDC (2008). Grain Legume Handbook – Weed control.

Photo 11: *Severe metsulfuron-methyl damage in chickpea plants.*

Source: DAFQ in Crop IT.

6.13.1 Avoiding herbicide damage

Some herbicides can severely damage chickpea crops through residues in soil, contaminants in spray equipment, spray drift onto the crop or by incorrect use of the herbicide.

The importance of cleaning and decontaminating spray equipment before the application of herbicides cannot be over-stressed. Traces of sulfonylurea herbicides (such as chlorsulfuron, metsulfuron, or triasulfuron) in spray equipment can cause severe damage to chickpea and other legumes when activated by grass control herbicides.

Taking some general precautions can help to reduce the likelihood of crop damage with residual herbicide use at planting:

- Do not apply residual herbicides if rain is imminent.
- Maintain at least 7.5–10 cm soil coverage.
- Avoid leaving a furrow or depression above the seed that could allow water (and chemical) to concentrate around the seed or seedling.
- Avoid leaving an exposed, open slot over the seed with disc-openers and avoid a cloddy, rough tilth with tined-openers. [41]

MORE INFORMATION

Field crop herbicide injury: The Ute Guide

Chickpea Disorders: The Ute Guide

6.13.2 Plant-back intervals

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop.

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods (e.g. sulfonylureas (chlorsulfuron)). This is shown in the Table 21 and 22 where known. Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the "Protection of crops etc." heading in the "General Instructions" section of the label.

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [42]

41 Pulses Australia. Chickpea Production: Southern and Western regions. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

42 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

Table 21: *Residual persistence of common pre-emergent herbicides, and note residual persistence in broad-acre trials and paddock experiences.* [43]

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks.
Glean® (chlorsulfuron)	28-42	High. Persists longer in high pH soils. Weed control longer than Logran.
Diuron	90 (range 1 month to 1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed longlasting activity on grass weeds such as black/stink grass (Eragrostis spp.) and to a lesser extent broadleaf weeds such as fleabane.
Atrazine	60–100, up to 1 year if dry	High. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane.
Simazine	60 (range 28–149)	Med./high. 1 year residual in high pH soils. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane.
Terbyne® (terbulthylazine)	6.5–139	High. Has had observed long lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed long lasting activity on grass weeds such as black/stink grass (Eragrostis spp.).
Stomp® (pendimethalin)	40	Medium. 3–4 months residual.
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months residual.
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Has had observed long lasting (> 6 months) activity on broadleaf weeds such as fleabane and sow thistle.

43 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event.
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than Trifluralin and Boxer Gold, however, weed control persists longer than Boxer Gold.

Table 22: *Minimum re-cropping intervals and guidelines (NOTE: always read labels to confirm).*

Group and type	Product	pH (H2O) or product rate (ml/ha) as applicable	Minimum re-cropping interval (months after application), and conditions
B, sulfonyl urea (SU)	Chlorsulfurons eg Glean®, Seige®, Tackle®	<6.5	3 months
		6.6–7.5	3 months, minimum 700 mm
		7.6–8.5	18 months, minimum 700 mm
B, sulfonyl urea (SU)	triasulfuron, eg Logran®, Nugrain®	7.6–8.5	12 months, >250 mm grain, 300 mm hay
		>8.6	12 months, >250 mm grain, 300 mm hay
B, Sulphonamide	Flumetsulam eg Broadstrike®		0 months
B, sulfonyl urea (SU)	metsulfuron eg Ally®, Associate®	5.6–8.5	1.5 months
		>8.5	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area.
B, sulfonyl urea (SU)	Metsulfuron + thifensulfuron Eg Harmony® M	7.8–8.5 Organic matter >1.7%	3 months
		>8.6 or organic matter <1.7%	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area.
B, sulfonyl urea (SU)	Sulfosulfuron eg Monza®	<6.5	0 months
		6.5–8.5	10 months

Source: Pulse Australia

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate

MORE INFORMATION

Avoiding crop damage from residual herbicides

plant-back heading or under the "Protection of crops etc." heading in the "General Instructions" section of the label. [44]

Conditions required for breakdown

Warm, moist soils are required to breakdown most herbicides through the processes of microbial activity. For the soil microbes to be most active they need good moisture and an optimum soil temperature range of 18°C to 30°C. Extreme temperatures above or below this range can adversely affect soil microbial activity and slow herbicide breakdown. Very dry soil also reduces breakdown. To make matters worse, where the soil profile is very dry it requires a lot of rain to maintain topsoil moisture for the microbes to be active for any length of time.

For up-to-date plant-back periods, see Weed control in winter crops.

6.14 Herbicide residues

Pulse growers need to be aware of possible herbicide residues that may affect crop rotation choices or cause crop damage. Herbicide residue impacts are more pressing where rainfall has been minimal. After a dry season, herbicide residues from previous crops could influence choice of crop and rotations more than disease considerations. The opposite occurs after a wet year.

Pulse crop types differ in their sensitivity to residual herbicides, so check each herbicide used against each pulse type. Residues of sulfonylurea herbicides can persist in some soils. These residues can last for several years, especially in more alkaline soils and where there is little summer rainfall. The pulses emerge and grow normally for a few weeks, and then start to show signs of stress.

Picloram (e.g. Tordon® 75-D) residues from spot-spraying can stunt any pulse crop grown in that area. This damage is especially marked in faba beans, where plants are twisted and leaves are shrunken. In more severe cases, bare areas are left in the crop where this herbicide had been used, in some cases more than five years ago. Although this damage is usually over a small area, correct identification of the problem avoids confusion and concern that it may be some other problem such as disease.

In wheat–chickpea rotations, the use of fallow and in-crop residual herbicides such as Broadstrike®, Eclipse®, Flame® Grazon®DS, Lontrel® and metsulfuron (Ally®, Associate®, Lynx®) Harmony®M should be avoided.

The use of long-term residual sulfonylurea herbicides such as Monza®, chlorsulfuron (Glean®, Lusta®), and Logran® in wheat should be avoided when re-cropping to chickpeas. [45]

Stay up to date with chemical labels and recommendations by visiting the APVMA and PubCRIS websites.

6.14.1 Sulfonylurea residues, Group B

Sulfonylurea products include:

- metsulfuron (Ally®, Associate®, Lynx®)
- thifensulfuron plus metsulfuron (Harmony®M)
- sulfosulfuron (Monza®)
- chlorsulfuron (Glean®, Lusta®,
- triasulfuron (Hussar, Atlantis, Logran®)

Usually, Glean®,or Logran® damage is not serious when these products are used as directed, although there is an increased risk of damage given:

- very dry or drought conditions

44 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/general-information/pre-emergent-herbicides

45 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

- highly alkaline (pH >8.5) soils
- excessive overlapping during application.

Sulfonylurea breakdown occurs by hydrolysis, and is favoured by warm, moist conditions in neutral to acid soils. Residues will tend to persist for longer periods under alkaline and/or dry conditions. Persistence of residues is greater for Glean® and Logran®, than for Ally® or Harmony®M.

Residues are root absorbed and translocated to the growing points; therefore, both roots and shoots are affected.

Moderate residue levels

Plant emergence will be patchy, and the first true leaves elongated and narrow. Plants remain stunted, with severe chlorosis of the uppermost leaves (Photo 12).

Photo 12: *Yellowing of new growth (left) and plant stunting (right).*

Photo: A. Storrie, NSW DPI.

Seedlings develop symptoms as the roots reach the sulfonylurea residue layer in the soil. This may occur in the early seedling stage on heavy clay soils, or slightly later on light sandy soils due to movement of residues down the soil profile. Symptoms are often more severe where there is soil compaction, e.g. in wheel tracks.

Symptoms include:

- spear-tipping of lateral roots (root pruning)
- yellowing of uppermost leaves, which can progress to older, lower leaves in severe cases.
- development of zinc-deficiency symptoms—narrow, cupped leaves
- stunted growth

Highly sensitive crops (in order of susceptibility)

- lentils
- chickpea (0.5 ppb)

Highly susceptible indicator weeds

- brassicas (turnip, mustard, radish)
- red pigweed, mintweed
- native jute
- parthenium weed
- paradoxa grass

Strategy

Avoid using Glean® or Logran® on very high pH soils (pH >8.5) if you intend growing chickpeas after wheat. Reassess risk if Glean® or Logran® has been used and drought conditions have been experienced during the wheat crop and in the subsequent fallow. [46]

6.14.2 Imidazolinone (imi) residues, Group B

Imidazolinone products include:

- imazapic + imazapyr (Midas®, OnDuty®)
- imazamox + imazapyr (Intervix®)
- imazapic (Flame®)
- imazethapyr (Spinnaker®, various imazethapyrs)
- imazamox (Raptor®)

Photo 13: *Spinnaker injury to the emerging new chickpea growth.*

Photo: G. Cumming, Pulse Australia.

Imazethapyr (e.g. Spinnaker®) can be damaging (Photo 13). Damage from residues of other 'imi' products should not be serious when used as directed, although there is an increased risk of damage where:

- plant-back periods or rainfall requirements are not adhered to;
- very dry or drought conditions have prevailed (often 150-200 mm rainfall required);
- soils are highly alkaline (pH >8.5);
- extensive overlapping has occurred during application; or
- heavy rainfall after application concentrates treated soil in plant furrows.

Persistence of imi residues is greater for Intervix® and Midas® or OnDuty® than for Flame®.

Residues are root-absorbed and translocated to the growing points; therefore, both roots and shoots are affected.

46 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Moderate residue levels

Plant emergence will be patchy, and the first true leaves elongated and narrow. Plants remain stunted, with severe chlorosis of the uppermost leaves.

Low residue levels

Seedlings develop symptoms as the roots hit the imi residue layer in the soil. This may occur in the early seedling stage on heavy clay soils, or slightly later on light sandy soils due to movement of residues down the soil profile. Symptoms are often more severe where there is soil compaction, such as in wheel tracks.

Symptoms include:

- spear-tipping of lateral roots (root pruning)
- yellowing of uppermost leaves, which can progress to older, lower leaves in severe cases
- development of zinc-deficiency symptoms—narrow, cupped leaves
- stunted growth

Highly sensitive crops (in order of susceptibility)

- conventional canola
- lentils
- safflower
- oats

Strategy

Avoid using imi products on very acidic soils if you intend growing chickpeas after a Clearfield® wheat or canola in an area with marginal rainfall. Reassess risk if imi products have been used and drought conditions have been experienced during the prior wheat, canola crop or fallow. Be wary of using imi products in short-term chemical fallows or for summer weed control where chickpeas are to be sown. [47]

6.14.3 Triazine residues (atrazine), Group C

Chickpeas have some tolerance to very low rates of atrazine, but triazine carry-over from previous crops should be avoided (see Photo 14). Atrazine significantly increases the frost sensitivity of the crop. Risk of damage increases where there are low levels of subsoil moisture. Crops in this situation are largely surface-rooted and vulnerable to damage when there is herbicide recharge after each rainfall event.

Photo 14: *Narrowing of the leaflets and multiple branching are signs of triazine residues (left). Similar distortion is seen in the roots (right).*

Photo: G. Cumming, Pulse Australia.

Atrazine breakdown is strongly influenced by soil type and climatic conditions. Rates of breakdown slow considerably under dry conditions, and can stop altogether under drought.

47 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Atrazine is more persistent under the following conditions:

- alkaline soils (especially pH >8.0)
- increasing clay content (i.e. black earths)
- low soil temperatures
- low soil moisture levels.

Atrazine is root-absorbed and translocated up into the shoots, where it accumulates and inhibits photosynthesis. Plants usually emerge, but begin to show symptoms of stunting and chlorosis at 2–6 weeks of age. Atrazine initially accumulates in the tips and margins of the lower leaves. This results in bleaching and necrosis of the leaf margins. Plants are often stunted and plant growth is slow. Other Group C herbicides such as diuron and fluometuron cause similar symptoms, mainly on the older, lower leaves.

Highly susceptible indicator weeds

- mintweed (turnip, mustard, radish)
- brassicas
- black pigweed. [48]

6.14.4 Group I

Products include:

- 2,4-D products (amines, esters)
- dicamba (e.g. Cadence®)
- triclopyr (e.g. Garlon®)
- fluroxypyr (e.g. Lontrel®)

Residues of 2,4-D persist for a relatively short period, and they can be overlooked. Photo 15 shows residual damage from 2,4-D. There are plant-back periods for various rates of products, but the most important value is the minimal rainfall requirement prior to sowing. In 2006, there was significant 2,4-D damage in chickpeas resulting from an application of a 2,4-D product as a late fallow spray and/or knockdown spray prior to sowing. The damage was due to not having received the minimal rainfall requirement of 15 mm before this period commenced. [49]

48 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

49 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Photo 15: *Residual 2,4-D damage, showing narrowing and thickening of leaflets on younger growth.*

Photo: J. Flemming, NSW DPI.

6.14.5 Group I residual herbicides

Products include:

- clopyralid (Lontrel®)
- picloram (Tordon® 75-D, Tordon® 242, Grazon® DS)
- aminopyralid + fluroxypy (e.g. Hotshot®)

These products are used for in-crop or fallow weed control and can persist for long periods under dry conditions. Lontrel® is used in canola, wheat, barley, triticale and oats, so care with a subsequent chickpea crop is required. It can persist on crop stubble for long periods and then it can become activated when leached into the soil following rainfall. Lontrel® is being used more often for residual control of fleabane. Picloram residues are relatively stable in the soil, with residues fixed onto clay particles and remaining concentrated in the top 10–15 cm of soil. Residues are slowly broken down by microbial action, with decomposition slowing during the colder, winter months. Up to 25% of the applied dose can persist for up to 12 months, or longer under very dry conditions.

Some symptoms of low-level residue damage are not always readily visible in chickpeas, for example:

- retarded, slow growth
- thickening and callousing of the lower stem, usually just above ground level, which can be accompanied by cracking and splitting of the stem in more severe cases
- proliferation of short, lateral roots.

There may also be some slight twisting and bending of the main stem. Higher rates of residue can also affect leaf shape, with a narrowing and thickening of leaflets. A severe reaction may cause cupping and stunting of leaflets.

Strategy

Avoid using Lontrel® or Grazon® DS in the fallow period prior to chickpeas. [50]

6.14.6 Management of herbicide residues in the soil

Using soil-persistent herbicides can provide very effective weed control; however, issues can arise when sensitive crops are planted in the next season. The main factors that influence whether crop damage occurs are: rainfall from application to sowing, temperature when the soil is wet, soil pH, soil organic matter, the sensitivity of the crop to the herbicide, and the relative persistence of the herbicide in the soil. Risk of damage to subsequent crops is greatest when conditions after application are dry from spring until autumn.

Herbicides can be broken down by chemical and/or microbial means. Both require moisture and temperature to be effective. Herbicides break down more slowly in winter when moisture may be available, but temperatures are low. In a Mediterranean climate, there is usually little or no herbicide breakdown over summer, where temperature is high, but there is no moisture available in the top soil. Most herbicide breakdown will occur in spring and autumn.

To achieve sustained breakdown of herbicides, the top 2 cm of the soil needs to be moist for a period of seven days or more. This is because in summer, the soil microbes shut down due to lack of water and it takes time for their populations to build up again. Small rainfall events in summer will be quickly evaporated from the topsoil, so as a general rule the rainfall events of less than 10 mm in summer should not be counted towards the amount of rainfall required for herbicide breakdown. It is those larger events, typically those of 25 mm or more, which will contribute most to herbicide breakdown.

Soil type and soil pH are also important, as they will affect how far the herbicide moves down the soil profile. Most of the microbial activity occurs in the top few centimetres of the soil and if the herbicide moves below this layer, it may be broken down more slowly. For example, sulfonylurea herbicides are much more mobile in alkaline soils, and this contributes to their longer persistence in alkaline soils. Soil organic matter is important as it provides food for the microbes. Microbial populations are typically smaller in soils with low organic matter than in those with higher organic matter.

Following a dry spring and summer, it is generally those large rainfall events in autumn that do most of the work in breaking down herbicides. The larger these events are and the earlier they occur, the lower the risk of crop damage. One added risk is that the first large rainfall event after a long dry summer will release herbicides into the soil water quickly. Planting too soon after that first large rainfall event can result in greater crop damage than waiting for a week to sow. The re-cropping intervals on product labels are a good guide to the likely risks of crop damage. When in doubt, it is good practice to sow a more tolerant crop. [51]

6.15 Herbicide resistance

Herbicide resistance fact box

- Resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a 'wild type' individual of the same species.

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50 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

51 GRDC Update Papers. (2016). Can we beat grass weeds or will they beat us. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/08/Can-we-beat-grass-weeds-or-will-they-beat-us

- Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide mode-of-action (MOA).
- As at June 2014, Australian weed populations have developed resistance to 13 distinct MOAs (click here for up to date statistics).
- Herbicide-resistant individuals are present at very low frequencies in weed populations before the herbicide is first applied.
- The frequency of naturally resistant individuals within a population will vary greatly within and between weed species.
- A weed population is defined as resistant when a herbicide at a label rate that once controlled the population is no longer effective (sometimes an arbitrary figure of 20% survival is used for defining resistance in testing).
- The proportion of herbicide resistant individuals will rise (due to selection pressure) in situations where the same herbicide MOA is applied repeatedly and the survivors are not subsequently controlled.
- Herbicide resistance in weed populations is permanent as long as seed remains viable in the soil. Only weed density can be reduced, not the ratio of resistant-to-susceptible individuals. The exception is when the resistance gene(s) carry a fitness penalty so that resistant plants produce less seed than susceptible ones, but this is rare. [52]

Herbicide resistance is the inherited ability of an individual plant to survive a herbicide application that would kill a normal population of the same species. During the 1940s and '50s, Australian agriculture relied heavily on the use of broad-spectrum pesticides to control pests. Selective herbicides began to appear in the mid-1970s and have been a fundamental tool for cropping and pasture since. However, as reliance on chemicals has grown over the years we are continuing to see more weeds that have developed resistance to herbicides. In other words, a number of chemicals that we have available to us have become less useful. Herbicide resistance was first recognised in Australia in 1981 where some annual ryegrass developed resistance to diclofop-methyl (Figure 3). [53]

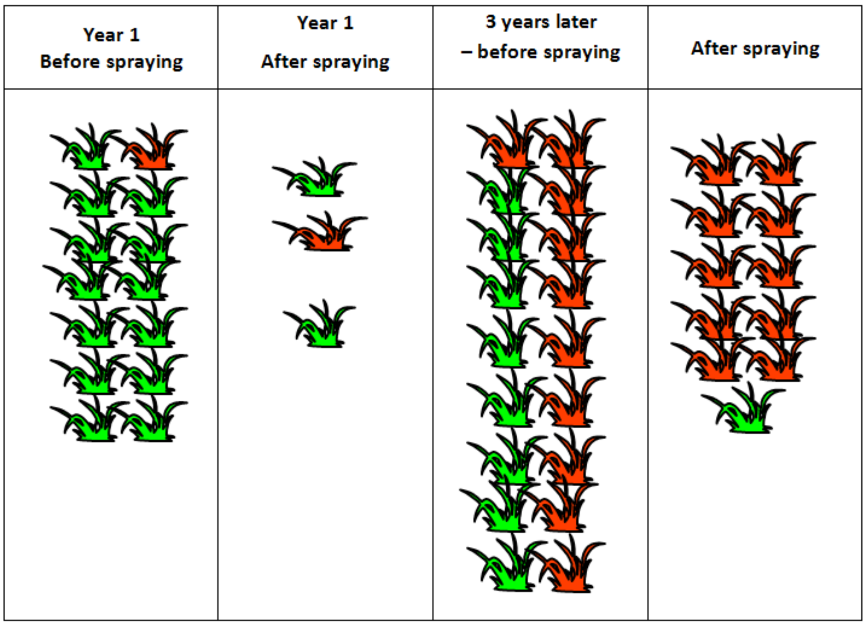

Figure 3: *How a weed population becomes resistant to herbicides.*

Source: GRDC.

52 GRDC. Integrated weed management hub – Section 1: Herbicide resistance. https://grdc.com.au/resources-and-publications/iwmhub

53 Agriculture Victoria. HERBICIDE RESISTANCE AND INTEGRATED WEED MANAGEMENT (IWM) IN CROPS AND PASTURE MONITORING TOOLS. http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

Herbicide use since the 1980s has seen the development of herbicide resistance across Australia in a range of cropping weeds, including annual ryegrass, wild oats, Indian hedge mustard, wild radish, wild turnip, and prickly lettuce as well as barley grass and capeweed (Table 23). Herbicide resistance is a major threat to Australian grain growers, but whilst herbicide resistance is here to stay, it need not spell the end of profitable cropping. Delaying the onset and/or reducing the impact of herbicide resistant weed populations calls for the implementation of a wide range of weed control strategies, that will in turn help sustain profitable grain production. [54]

Table 23: *Resistance status of a number of weeds. Note: Resistance status will vary from paddock to paddock and not all populations have these characteristics.*

Weed species	Resistance status
Annual Ryegrass (*Lolium rigidum*)	Very high resistance to Group A (e.g. Diclofop) and Group B herbicides (Sulfonylureas). Some resistance to Group D (Trifluralin) and Glyphosate (Group M herbicides).
Wild Oat (*Avena fatua*)	Diclofop-methyl (Group A herbicides) resistance Resistance to Group K (flamprop-methyl)
Barley grass (*Hordeum leporinum*)	Paraquat and Diquat resistance
Capeweed (*Arciotheca calendula*)	Paraquat and Diquat resistance
Barnyard Grass (*Echinochloa crus-galli*)	Resistance to Group C herbicides
Wild Radish	Resistance to chlorosulfron has increased threefold over last four years. Some resistance to Atrazine and 2, 4-D-amine.
Brome grass (*Bromus* spp.)	Resistant to Group A (Verdict) and Group B imi resistance.
Indian hedge mustard, prickly lettuce, wild turnip, sow thistle, black bindweed, silvergrass, summer grass, salvation jane.	New additions of resistant weeds with resistance to one or more groups of herbicides.

Source: AgVic.

Annual ryegrass herbicide resistance

A number of weed species have developed resistance to herbicides. Of the greatest concern is Annual Ryegrass (*Lolium rigidum*) because it has developed cross-resistance to a number of different herbicide groups. Annual Ryegrass is one of the most significant weeds for cropping enterprises—and we are rapidly running out of chemical options to deal with it. Table 26 shows the resistance status of Annual Ryegrass to a number of Group A, B, D, and M herbicides—a herbicide program made up of two to three years use of any of these can fail due to cross resistance. Resistance to trifluralin is increasing rapidly and is high in many areas of South Australia.

54 GRDC (2008). Grain Legume Handbook – Weed control

Table 24: *Estimated number of herbicide applications before resistance develops.*

Product	Low ryegrass number	High ryegrass numbers
Group A	7 to 10	4
Group B		4
Group D (trifluralin)	15	10
Group L		12
Group M		15
Double Knock		30 +

Source: PIR.SA.

Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide 'mode of action' (MOA) group (Photo 16).

Photo 16: *Pots of annual ryegrass tested for plyphosate resistance; susceptible (left) and strongly resistance (right).*

Photo: Peter Boutsalis, Source: DAFWA.

Herbicide resistance is normally present at very low frequencies in weed populations before the herbicide is first applied. Variation exists within every population, with some individuals having the ability to survive the herbicide application.

A weed population is defined as resistant when a herbicide that once controlled the population is no longer effective (sometimes an arbitrary figure of 20% survival is used). The proportion of herbicide resistant individuals will rise due to selection pressure in situations where one herbicide MOA group is applied repeatedly. [55]

An evaluation of farming systems in low rainfall areas has found that (Table 25):

- As cropping intensity increased, higher average returns are possible, but it is imperative to reduce the number of ryegrass to a very low level prior to, or as soon as possible in the rotation and then using a full range of practices to keep the number low.
- The initial reduction in ryegrass numbers must be carried out with as little selection for resistance as possible. Selective herbicide can be used without the population of ryegrass increasing its resistance if spray topped or green manured before seed set.
- To avoid the build-up in resistance to Group M (glyphosate), the additional cost of the double knock system is justified, particularly in more intensive systems that rely on glyphosate for early weed control in rotations.

55 DAFWA. (2016). Herbicide resistance. https://www.agric.wa.gov.au/grains-research-development/herbicide-resistance?page=0%2C0

- Ryegrass numbers also compete strongly with the crop limiting yield and returns (Photo 17).

Table 25: *Percent Ryegrass Control with different management treatments.*

Treatment	Average % Control Resistant Population	Average % Control
Trifluralin®	30 to 40	80
Trifluralin® + Avadex®	75	85
Boxer Gold®	80 to 90	80 to 90
Sakura®	80 to 90	80 to 90
Double knock (application of glyphosate followed by Sprayseed three days later)	40%	40%
Crop topping		75%
Spray topping (low rate of paraquat or glyphosate) at flowering / milky dough		70%
Brown manure (high rate of glyphosate)		95%
Hay cutting		85%
Stubble burning – grazed		40%
Stubble burning – standing stubble ungrazed		75%
Windrow burning in canola, lupins and beans	85	85% plus
Wheat stubbles from < 2.5 t/ha grain crops		85% plus
Burning chaff dumps		90%
Seed catching		60%
Harrington seed destructor		95%

Source: PIR.SA

Photo 17: *Glyphosate resistant annual ryegrass in crop paddock.*

Source: GRDC.

6.15.1 Herbicide resistant annual ryegrass in the Wimmera and the Mallee

Random resistance surveys have shown that herbicide resistance in annual ryegrass is increasing in Victoria. Randomly selected paddocks in the Wimmera and Mallee were surveyed for resistant weeds in 2015. For annual ryegrass, particular concern is with increasing resistance to trifluralin, Intervix, and glyphosate (Table 26). While trifluralin resistance is becoming widespread in annual ryegrass, we picked up no resistance to any of the other pre-emergent herbicides tested. Glyphosate resistance is now common enough to be picked up in our random weed surveys.

Table 26: *Extent of herbicide resistance in annual ryegrass collected in random surveys in Wimmera and Mallee in 2015. Populations are considered resistant if there is more than 20 per cent survival.*

Herbicides tested	Group	Annual ryegrass populations resistant (%)	
		Wimmera	Mallee
Trifluralin	D	36	23
Boxer Gold®	J + K	0	0
Sakura®	K	0	0
Propyzamide	D	0	0
Hoegrass®	A	80	47
Oust®	B	53	68
Intervix®	B	21	44
Axial®	A	46	10
Select®	A	10	0
Glyphosate	M	9	3

Source: GRDC.

6.15.2 Brome grass resistance rising

Brome grass (Photo 18) is proving to be a headache for grain growers across southern Australia with more plants showing resistance to Group B herbicides. University of Adelaide reports an increasing number of brome grass plants are showing herbicide resistance across the southern and western grain growing districts of Victoria, South Australia, and Western Australia.

Photo 18: *The two main problem species of brome grass in Australia; Diandrus (left) and Rigidous (right).*

Source: GRDC.

Researchers have been collecting brome grass seed samples from fields where farmers were suspicious that herbicide resistance may be the cause of poor herbicide performance.

Samples collected from across the South Australian Mallee region were tested for resistance to current registered herbicides and the tests revealed a high level of herbicide resistance in these weed populations. Herbicide resistance was identified in around 50% of the samples tested.

As well as the South Australian Mallee, brome grass is a significant weed in the Victorian Mallee, Upper Eyre, and in Western Australia. [56]

Integrated management of brome grass

Integrated management of brome grass is much more difficult than integrated management of annual ryegrass. Imidazolinone herbicides, such as Intervix remain the best herbicide options available for brome grass; however, they are Group B herbicides and at high risk of resistance. Trials were conducted, exploring integrated management strategies for brome grass at Balaklava in South Australia over the past three years. The trial consisted of four crop options in rotation with two strategies in each of the crops (Table 27). Clearfield options were used for the cereal phase of the rotation.

56 WeedSmart. 2014. Brome Grass resistance rising – Southern Australia. http://www.weedsmart.org.au/bulletin-board/brome-grass-resistance-rising/

Table 27: *Herbicide strategies investigated for the management of brome in lupins, TT-canola, wheat and barley at Balaklava.*

*Cropping phase	Herbicide strategy (1 & 2)	
	HS1	HS2
Lupins	Simazine pre Haloxyfop post	Simazine pre Haloxyfop post Paraquat crop-top
TT-canola	Atrazine pre Atrazine[ϕa]plus Haloxyfop post	Propyzamide pre Atrazine plus Haloxyfop post Glyphosate crop-top
Wheat	Trifluralin pre Intervix post	Sakura plus Avadex Xtra pre Glyphosate[ϕb] crop-top
Barley	Trifluralin plus metribuzin pre	Trifluralin pre Intervix post

*Wheat and barley cultivars are tolerant to imidazolinone herbicides.

[ϕa]Listed on the label as having suppression of brome grass; [ϕb]Weedmaster DST is the glyphosate product registered for this use.

The two break crops in the rotation were able to reduce the brome grass seed bank, regardless of the strategy used. However, for cereals, the brome grass seed bank was only reduced when Clearfield crops and Intervix herbicide were used (Figure 4). Previous research has demonstrated that you need two consecutive years of good control of brome grass to manage this weed species. Where we had back-to-back break crops (lupins followed by canola) followed by a Clearfield cereal, we were able to reduce brome grass seed production in 2015 to zero. Clearly it is important to use the last remaining Intervix applications on brome grass in the cereal part of the rotation and following a break crop to achieve the best long term result. [57]

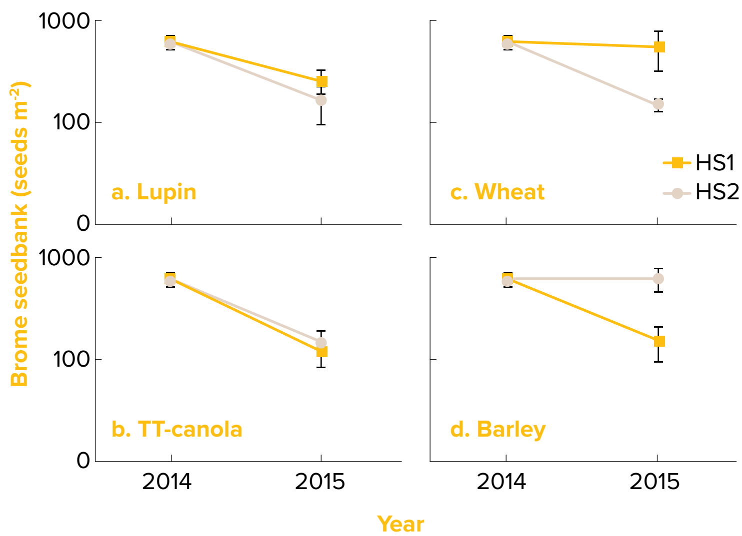

Figure 4: *Change in brome grass seed bank in response to herbicide strategy (HS1 and HS2) in lupin (a), TT-canola (b), wheat (c), and barley (d) crop phases at Balaklava in 2015. Vertical bars represent SE. The initial brome grass seed bank was 626 seeds/m.*

Source: GRDC.

57 GRDC Update Papers. (2016). Can we beat grass weeds or will they beat us. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/08/Can-we-beat-grass-weeds-or-will-they-beat-us

Glyphosate resistance

Glyphosate resistance was first documented for annual ryegrass (Lolium rigidum) in 1996 in Victoria. Since then, glyphosate resistance has been confirmed in 11 other weed species (Figure 5).

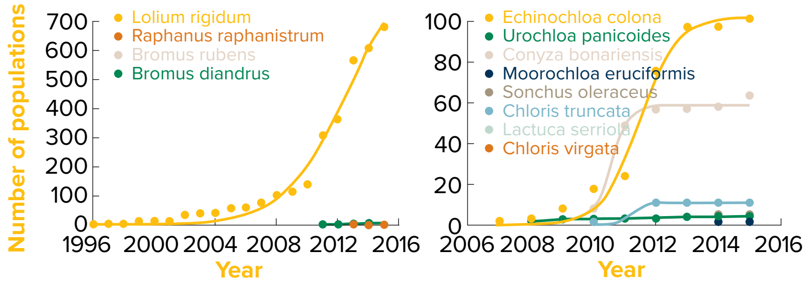

Figure 5: *Increase in confirmed cases of Glyphosate resistance in winter weeds (left) and summer weeds (right) between 1996 and 2016.*

Source: AGSWG.

Resistance is known in eight grass species and four broadleaf species. There are four winter-growing weed species and eight summer-growing weed species. The latter have been selected mainly in chemical fallows and on roadsides.

The most number of resistant populations is for annual ryegrass (Table 28) followed by barnyard grass and then fleabane.

Table 28: *Glyphosate resistant annual ryegrass has occurred in the following situations.*

Situation		Number of Sites	States
Broadacre cropping	Chemical fallow	34	NSW
	Winter grains	393	SA, Vic, NSW, WA
	Summer grains	1	NSW
	Irrigated crops	1	SA
Horticulture	Tree crops	10	SA, NSW
	Vine crops	25	SA, WA
	Vegetables	2	Vic
Other	Driveway	6	SA, Vic, NSW, WA
	Fenceline/crop margin	91	SA, Vic, NSW, WA
	Around buildings	2	NSW
	Irrigation channel/ drain	14	SA, Vic, NSW
	Airstrip	1	SA
	Railway	2	NSW, WA
	Roadside	95	SA, NSW, WA
	Pasture	1	WA

Source: AGSWG.

All of the glyphosate-resistant weed populations have occurred in situations where there has been intensive use of glyphosate, often over 15 years or more, few or no other effective herbicides used and few other weed control practices are used. This suggests the following are the main risk factors for the evolution of glyphosate resistance:

- 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 controls [58]

6.15.3 Practices to minimise herbicide resistance

The threat of herbicide resistance does not mean that herbicides should not be used; however, it does mean farmers should avoid over reliance on herbicides that have the same action on plants ("mode of action"). All herbicide labels now indicate what herbicide group the active ingredient belongs to. Cases of glyphosate resistance in annual ryegrass and of paraquat resistance in barley grass in direct-drill cropping systems sounds a warning on heavy reliance on even "low risk" herbicides.

Growers should aim to use as many different methods of weed control as practical in the overall paddock management including the following:

- rotation of cultivation and herbicide groups
- crop competition
- use of knockdown
- pasture topping herbicides for seedset
- hay making preparation
- grazing
- burning
- seed capture
- crop-topping
- weed wiping (short crops)

Care must be taken when introducing control methods into the overall paddock plan. For example, weed numbers, especially resistant populations, can increase dramatically under pulses due to the poor competition offered by these crops.

Monitoring of weed populations before and after spraying is an important management tool.

Field testing and/or seed testing, as well as planning management strategies, can provide a guide to the resistance status of weed populations. [59]

6.15.4 WeedSmart farming

The Australian grain industry stands at the crossroads with two options. Which direction will it take?

One road is for every grower to make herbicide sustainability their number one priority so that it influences decision-making and practices on all Australian grain farms. Armed with a clear 10-point plan for what to do on-farm, grain growers have the knowledge and specialist support to be WeedSmart.

On this road, growers are capturing and/or destroying weed seeds at harvest. They are rotating crops, chemicals, and modes of action. They are testing for resistance and aiming for 100% weed kill, and monitoring the effectiveness of spray events.

In addition, they are not automatically reaching for glyphosate, they do not cut on-label herbicide rates, and they carefully manage spray drift and residues. Growers are planting clean seed into clean paddocks with clean borders. They use the double-knock technique and crop competitiveness to combat weeds. On this road, the

58 Australian Glyphosate Sustainability Working Group. (2016). Glyphosate resistant weeds in Australia. http://glyphosateresistance.org.au/RegisterSummary.pdf

59 GRDC (2008). Grain Legume Handbook – Weed control

industry stands a good chance of controlling resistant weed populations, managing difficult-to-control weeds, prolonging the life of important herbicides, protecting the no-till farming system, and maximising yields.

The other option is for growers to think resistance is someone else's problem, or an issue for next year, or something they can approach half-heartedly. If herbicide resistance is ignored, it will not go away. Managing resistance requires an intensive but not impossible effort. Without an Australia-wide effort, herbicide resistance threatens the no-till system, land values, yields, and your hip pocket. It will drive down the productivity levels of Australian farms.

Jump on board WeedSmart and take the road of least resistance.

WeedSmart 10-point plan

1. Act now to stop weed seed set

- Research and plan your WeedSmart strategy.
- Understand the biology of your weeds.
- Be strategic and committed.

2. Capture weed seeds at harvest

- Consider your options—chaff cart, narrow windrow burning, baling, Harrington Seed Destructor.
- Compare the financial cost per hectare.

3. Rotate crops and herbicide modes of action

- Protect the existing herbicide resource.
- Repeated application of effective herbicides with the same MOA is the single greatest risk factor for herbicide resistance evolution.

4. Test for resistance to establish a clear picture of paddock-by-paddock farm status

- Resistance continues to evolve.
- Sample weed seeds prior to harvest for resistance testing.

5. Never cut the rate

- Always use the label rate.
- Weeds resistant to multiple herbicides can result from below the rate sprays.

6. Don't automatically reach for glyphosate

- Consider diversifying
- Consider post-emergent herbicides where suitable.
- Consider strategic tillage.

7. Carefully manage spray events

- Use best management practice in spray application.
- Patch spray area of resistant weeds if appropriate
- No escapes

8. 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.

9. Use the double knock technique

- Any combination of weed control that involves two sequential strategies
- A second application to control survivors from the first

10. Employ crop competitiveness to combat weeds

- Increase your crop's competitiveness to win the war against weeds.
- Row spacing, seeding rate, and crop orientation can all be tactics to help crops fight. [60]

VIDEOS

10. Double knock application – a Grower's Experience.

MORE INFORMATION

WeedSmart Southern Region Guide.

60 WeedSmart 10 point plan. http://www.weedsmart.org.au/10-point-plan/

6.15.5 Testing for herbicide resistance

There are a number of different methods of testing for herbicide resistance. Tests can be performed in-situ (in the paddock during the growing season), on seed collected from the suspect area or by sending live plant samples to a testing service.

Testing can be conducted on-farm or by a commercial resistance testing service.

In-situ testing

An in-situ test can be performed following herbicide failure in a paddock. The test should be done at the earliest opportunity, remembering that the weeds will be larger than when the initial herbicide was applied. Test strips should be applied using herbicide rates appropriate to the current crop growth stage and weed size, plus a double rate. The test strips should only be applied if the weeds are stress free and actively growing. To more accurately assess the level of control, conduct weed plant counts before and after application. Green or dry plant weights can be calculated for more accurate results.

Herbicide resistance seed tests

Seed tests require collection of suspect weed seed from the paddock at the end of the season. This seed is generally submitted to a commercial testing service.

Approximately 3000 seeds of each weed (an A4-sized envelope full of good seed heads) is required for a multiple resistance test. This equates to about one cup of annual ryegrass seed and six cups of wild radish pods.

Syngenta herbicide resistance Quick-Test™

The Syngenta herbicide resistance Quick-Test™ (QT) uses whole plants collected from a paddock rather than seeds, eliminating the problem of seed dormancy and enabling a far more rapid turnaround time. In addition, the tests are conducted during the growing season rather than out of season over the summer. A resistance status result for a weed sample is possible within four to six weeks. The QT, which was developed by Dr Peter Boutsalis while working for Syngenta in Switzerland, is patented in Australia.

For each herbicide to be tested, 50 plants are required. To reduce postage costs, plants can be trimmed to remove excess roots and shoots. Upon arrival at the testing service, plants are carefully trimmed to produce cuttings and transplanted into pots. After appearance of new leaves (normally 5–7 days), plants are treated with herbicide in a spray cabinet. The entire procedure, from paddock sampling to reporting results, takes between 4–6 weeks, depending on postage time and the herbicides being tested. Unlike paddock tests, the QT is performed under controlled conditions, so it is not affected by adverse weather conditions. The age of the plants is also less critical to the testing procedure. Trimming the plants prior to herbicide application means that herbicides are applied to actively growing leaves, thus mimicking chemical application to young seedlings. The Quick-Test™ has been used to test resistance in both grass and broadleaf weed species. During testing, both known sensitive and resistant biotypes are included for comparison.

Quick-Tests can be done with Peter Boutsalis, Plant Science Consulting. [61]

6.16 Grazing for weed control

Grazing is alternative non-chemical option in weed control (Photo 19). Most weeds are susceptible to grazing. Weed control is achieved through reduction in seed-set and competitive ability of the weed. The impact is optimised when the timing of the grazing is early in the life cycle of the weed.

61 DAFWA. (2016). Herbicide resistance. https://www.agric.wa.gov.au/grains-research-development/herbicide-resistance?page=0%2C0

Photo 19: *Sheep grazing pasture.*

Source: GRDC.

Plants vary in their palatability and that under the 'right' stocking rate, animals will selectively graze the more palatable plants. This knowledge is useful when previously grown crops volunteer in the sown crop and herbicides are not available or their use would damage the crop. For example, graze peas in a chickpea crop. The relative palatability for some crops has been determined by the University of Adelaide and are shown in Table 29. The palatability was rated as highly palatable—most of the crop eaten; low palatability—very little of the crop eaten.

For best results:

- introduce sheep early, before crop canopy closes;
- use older sheep;
- use low stocking rates;
- spray weeds along fence line to concentrate sheep in crop;
- remove sheep before they do much damage to crop;
- remove sheep before flowering.

Observe grazing withholding periods if any chemicals are used in crop. [62]

Table 29: *Relative palatability of various crops to sheep.*

Highly palatable	Moderately palatable	Low palatability
Nine weeks after sowing		
Field peas, lathyrus, fenugreek, lentils, canola, wheat, safflower, lupin, blanchefleur, and Languedoc vetch.	Chickpeas	Coriander, faba beans, narbon bean
13 weeks after sowing		
Field peas, lathyrus, canola	Lentils, lupins	Chickpeas, coriander, faba beans, narbon bean, fenugreek

Source: GRDC.

62 GRDC (2008). Grain Legume Handbook – Weed control

6.16.1 Grazing stubbles or failed crops

When putting stock onto crop stubbles or failed crops, there are several considerations, the most important being:

- pulpy kidney
- acidosis, also known as grain poisoning
- nitrates or cyanides in weeds
- wind erosion of soil
- withholding periods

Some simple actions can overcome these issues:

- Ensure that stock have had their 5-in-1 vaccinations and boosters.
- Pulpy kidney is the weakest of the vaccines in 5-in-1, and it is cheap insurance to vaccinate again.
- Ensure that stock have a full rumen prior to going onto a crop.
- This can be easily done by providing hay or stubble as gut-fill.
- This will avoid over gorging on weeds or grain and give the rumen time to adjust to the change in feed.
- Spread large piles of grain out to minimise excessive intakes and risk of acidosis.
- Double-check previous crop chemical treatments and make sure all withholding periods are met before introducing stock.
- Slowly introduce stock to feed by allowing increasing periods over a week, starting with two hours.

Watch stock closely for the first week to ensure no problems occur, including unpalatability, which will result in decreased intake and loss of condition. [63]

63 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.