WESTERN

SEPTEMBER 2018

GRDC

GROWNOTES™

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

BARLEY

SECTION 6

WEED CONTROL

INTEGRATED WEED MANAGEMENT (IWM) | AGRONOMY | KEY WEEDS IN WA'S CROPPING SYSTEM | STOPPING WEED SEEDSET | HERBICIDE RESISTANCE | MANAGING THE WEED SEEDBANK | MANAGING WEED SEEDLINGS | HARVEST WEED-SEED CONTROL | OTHER NON-CHEMICAL WEED CONTROL | STRATEGIES TO STOP THE SPREAD OF WEEDS

MORE INFORMATION

GRDC (2015) Herbicide Innovation Partnership. Video.

GRDC Weed ID. the Ute Guide.

Natural Heritage Trust (2004) Introductory weed management manual.

WA Herbarium: FloraBase.

Weeds Society of WA: Western Weeds.

Weed control

Weeds have a direct financial impact on the farm business and the presence of weeds in the farming system can influence the decision to grow malt or feed type barley varieties. Competition with weeds not only decreases yield potential but it can cause malt barley varieties to be downgraded to feed through decreases in grain quality. [1]

Weeds are costing Australian grain growers on average $146/ha in expenditure and yield losses with the overall cost to Australian grain growers of $3.3 billion annually.

The overall annual cost to Western Australian grain growers is $927 million or $117/ha.

Reducing the cost of weed management is one of the grains industry's largest challenges. [2] To address this, the GRDC has invested $45 million over five years into a 'Herbicide Innovation Partnership' with Bayer CropScience which aims to discover and develop innovative weed management solutions. [3]

The GRDC also has a $1.5 million annual investment in the Australian Herbicide Resistance Initiative (AHRI), based at The University of Western Australia.

If you need advice on weeds please search the DAFWA website, Western Australian Organism List or contact the Pest and Disease Information Service (PaDIS).

For diagnostic services, please contact the AGWEST Plant Laboratories.

6.1 Integrated weed management (IWM)

Rapid expansion of herbicide resistance and the lack of new modes of action (MOA) means non-herbicide tactics must be a significant component of any farming system and weed-management strategy.

Inclusion of non-herbicide tactics is critical to prolong the effective life of remaining herbicides, as well as new products and MOA.

Effective herbicides are key components of profitable cropping systems. Protecting their efficacy directly contributes to future sustainability and profitability.

Successful weed management requires a paddock-by-paddock approach. Knowledge of weeds and weedbank status, soil types in relation to herbicide use, and cropping and pasture plans are critical parts of the picture. Knowledge of paddock history and of how much the summer and winter weeds have been subjected to selection for resistance (and to which herbicide MOAs) can also assist.

When resistance has been identified, knowledge of which herbicides are effective becomes critical.

The following five-point plan will assist in developing a management plan for each paddock:

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

1 B Paynter and A Hills (2007) Barley agronomy highlights: Weeds and row spacing. Agribusiness Crop Updates 2007, https://www.researchgate.net/publication/273135501_Barley_agronomy_highlights_Weeds_and_barley_variety

2 RS Llewellyn and D Ronning et al. (2016) Impact of Weeds on Australian Grain Production. Report for GRDC. CSIRO Australia, https://grdc.com.au/Resources/Publications/2016/03/Impact-of-weeds-on-Australian-grain-production

3 GRDC (2015) Boosting innovation capacities in weed control research. GRDC Media, https://grdc.com.au/Media-Centre/Media-News/National/2015/06/Boosting-innovation-capacities-in-weed-control-research

4 GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub

6.1.1 Review past actions

The historical level of selection pressure can be valuable information for managers to gauge which weed–MOA group management links are at greatest risk of breaking. Such knowledge can prompt more intensive monitoring for weed escapes when a situation of high risk exists. Picking up newly developing resistance issues while patches are still small and before they spread can mean a big difference in the cost of management over time.

From all available paddock records, calculate or estimate the number of years in which different herbicide MOAs have been used. The number of years is of far greater relevance than the number of applications in total. For most weeds, use of a herbicide MOA in two consecutive years presents a far greater selection pressure for resistance than two applications of the same herbicide MOA in one year. If the entire paddock history is unavailable to you, state what is known and estimate the rest. Collate separate data on MOA use for summer and winter weed spectrums. Further subdivide these into broadleaf and grass weeds.

Account for double-knocks. Where survivors of one tactic would have been largely controlled by the use of another tactic, reduce the number of MOA uses accordingly. An example might be as follows. Trifluralin (Group D) has been used 20 times, but there were 6 years when in-crop Group A selectives were used and several more years when in-crop Group B products (targeting the same weed as the trifluralin) were used. These in-crop herbicides effectively double-knocked the trifluralin, thus reducing the effective selection pressure for resistance to trifluralin.

Review the data you have collected and identify which weed–MOA groups have been selected for at a frequency likely to lead to resistance in the absence of a double-knock. Trifluralin typically takes about 10–15 years of selection for resistance to occur (Table 1). Thus, in the above example, a 'watching brief' would be in place for trifluralin and other Group D MOA herbicides.

Paddock history can provide useful information when evaluating the likely reasons for herbicide spray failures, in prioritising strategies for future use and in deciding which paddocks will receive extra time for scouting to find potential patches of weed escapes.

Information on MOA use history should be added to paddock records. [5]

Table 1: *Typical number of years of use of mode of action (MOA) groups before weeds develop resistance*

Herbicide group	Typical years of application	Resistance risk
A (fops/dims/dens)	6–8	High
B (sulfonylureas, imidazolinones)	4	High
C (triazines, substituted ureas)	10–15	Medium
D (trifluralin, pendimethalin)	10–15	Medium
F (diflufenican)	10	Medium
I (phenoxies)	>15	Medium
L (paraquat/diquat)	>15	Medium
M (glyphosate)	>12	Medium

5 GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub

MORE INFORMATION

[GRDC Webinars: Beginner's guide to harvest weed seed control]

[GRDC (2013) The effectiveness of on-farm methods of weed seed collection at harvest time: Case studies of growers in the Albany Port Zone]

See the WeedSmart website for more information: www.weedsmart.org.au

6.1.2 Assess the current weed status

Record the key broadleaf and grass weed species for summer and winter, and include an assessment of weed density, with notes on weed distribution across the paddock. Include GPS locations or reference to spatial location of any key weed patches or areas tested for resistance.

Include any data, observations or information relating to the known or suspected herbicide-resistance status of weeds in this paddock. Add this information to paddock records.

6.1.3 Identify weed management opportunities

Identify which different herbicide and non-herbicide tactics could be cost-effectively added to the system and at what point in the crop sequence these can be added. For further information on the different IWM tactics see: IWM Section 5: Tactics.

6.1.4 Combine and test ideas

Computer simulation tools can be useful to run a number of 'what if' scenarios to investigate potential changes in management and the likely effect of weed numbers and crop yield.

Combine ideas using a rotational planner, or test them by using decision-support software such as RIM and Weed Seed Wizard. [6]

Ryegrass integrated management (RIM)

The RIM decision-support software provides insights into the long-term management of annual ryegrass in dryland broadacre crops facing development of herbicide resistance. RIM enables growers to compare the cost and impact on weed numbers of alternative strategies and tactics for ryegrass management over time. The software's underlying model integrates biological, agronomic and economic considerations at paddock scale and over the short and long term.

The tool tracks the changes through time on a 10-year crop cycle for ryegrass seed germination, seed production and competition. Financial returns are also estimated annually and as a 10-year average return.

A free download is available from: http://www.ahri.uwa.edu.au/RIM.

6 GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub

MORE INFORMATION

NSW DPI (2016) Weed control in winter crops 2016.

NSW DPI (2012) Weed control in summer crops 2012–13.

S Trengrove (2015) New technology for improved herbicide use efficiency. GRDC Update Paper.

P Boutsalis et al. (2015) Optimising the impact of glyphosate. GRDC Update Paper.

P Newman (2015) Why the obsession with the ryegrass seed bank? GRDC Update Paper.

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, 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. [7]

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.

http://www.grdc.com.au/GCTV8-WeedSeedWizard

https://www.agric.wa.gov.au/weed-seed-wizard-0

6.1.5 Cultivation practices

The adoption of no-till farming in WA has increased the reliance of growers on integrated weed management systems. The predominant reason for adopting no-tillage in WA was soil conservation rather than weed control.

Most growers believe that whilst weed emergence will be lower under no-tillage there will be an increase in reliance on herbicides. No-tillage systems increase the need for herbicides due to the reduction in cultural weed control. Integrated weed management systems are therefore critical to the success of no-tillage systems, especially with the increase in resistance in annual ryegrass to post-emergent, selective herbicides and the risk of developing resistance to glyphosate.

The shift toward no-till farming has also been associated with an increase in stubble retention and the need for seeding machinery that can sow crops without blockage. An increase in crop row spacing may allow this. However, a potential consequence of increasing the row spacing is a decrease in grain yield. As well as affecting grain yield, a wide row spacing may favor weed biomass and weed seed set. [8]

6.2 Agronomy

Successful weed management relies on implementation of the best available agronomic practices to optimise crop environment and growth. A good starting point is to:

- Know the weed species and if unsure, seek advice
- Know the weed seed bank: are there low, medium or high levels of weed seeds in the soil (history)?
- Conduct in-crop weed audits prior to harvest to know which weeds may be problematic the following year.
- Ensure retained barley seed is from a clean paddock (Photo 1)

7 GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub

8 B. Paynter (2010) Wide Row Spacing and Rigid Ryegrass (*Lolium rigidum*) Competition Can Decrease Barley Yield. Weed Technology, 2010 24:310–318, https://www.researchgate.net/publication/232677235_Wide_Row_Spacing_and_Rigid_Ryegrass_Lolium_rigidum_Competition_Can_Decrease_Barley_Yield

- Have a crop-rotation plan that considers not just crop type being grown but also what weed control options the crop system may offer

Photo 1: *Ensure barley seed that is kept is from a clean paddock.*

Source: A. Mostead

6.2.1 Crop choice and sequence

Many agronomic and weed-management issues arise from the sequence in which crops are sown:

- Rotations provide options for different weed-management tactics
- Crop rotations can improve crop fertility
- Rotations can help manage disease and insects. Healthy crops are more competitive against weeds
- Many weeds are easier or more cost-effective to control in specific crops, pastures or fallows

The ability to compete with weeds varies between crop type and variety. In paddocks with high weed pressure, a competitive crop will enhance the reduction in weed seedset obtained through other weed-management tactics. It will also reduce the impact that surviving weeds have on crop yield and the quantity of seedset by any surviving weeds. [9]

Disease and weed management are linked and key decision points include:

- Selecting crop sequences and varieties to deal with the significant pathogens and nematode issues for each paddock
- Weeds are alternative hosts to some crop pathogens so effective weed management can reduce disease pressure
- Rhizoctonia can affect seedling crop growth, leaving the crop at greater threat from weed competition. Removing weeds for a period prior to sowing can significantly reduce the level of Rhizoctonia inoculum
- Weed growth in the fallow or in-crop can increase moisture use and exacerbate yield loss from diseases such as crown rot
- Residual herbicides used in the fallow or preceding crop may limit crop options

For a list of crop choice options to aid weed management, go to the tables within IWM Section 4: Agronomy.

9 GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub

FAQ

6.2.2 Improving crop competition

The impact of weeds on crop yield can be reduced and the effectiveness of weed-control tactics increased by crop competition. The rate and extent of crop canopy development are key factors influencing a crop's competitive ability with weeds. A crop that rapidly establishes a vigorous canopy, intercepting maximum sunlight and shading the ground and inter-row area, will provide optimum levels of competition.

The leaf area index at the end of tillering in barley is highly correlated with the crop's ability to compete with weeds. [10]

Differences in canopy structure in barley are generally more pronounced than those in modern wheat varieties. Barley varieties may differ in their early growth habit (i.e. prostrate, semi-erect and erect). They may also differ in their height at maturity by up to 40 cm, their leaf angle and shape (i.e. floppy, erect, large, skinny) and maturity group (with differences in flowering date of up to 4 weeks). [11]

Canopy development is influenced by:

- crop type and variety
- row spacing, sowing rate and sowing depth (Photo 2)
- crop nutrition
- foliar and root diseases
- nematodes
- light interception and crop row orientation

Photo 2: *Difference in crop competition between low (top) and high (bottom) seeding rates.*

Source: D. Minkey

Each factor will in turn affect plant density, radiation adsorption, dry-matter production and yield. Early canopy closure can be encouraged through good management addressing these factors.

10 GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub

11 B Paynter and A Hills (2007) Barley agronomy highlights: Weeds and row spacing. Agribusiness Crop Updates 2007, https://www.researchgate.net/publication/273135501_Barley_agronomy_highlights_Weeds_and_barley_variety

MORE INFORMATION

S Goss and R Wheeler (2015) Using crop competition for weed control in barley and wheat. GRDC Update Paper.

DAFWA (2016) East-west orientation for improved crop competition.

IWM Section 4: Agronomy.

Variety selection

Selecting the correct variety for a specific paddock can provide substantial yield improvements. If a stand-out variety in National Variety Trials (NVT) results is found, growers and advisers should check its performance under weed pressure to ensure it is suited to the growing conditions.

Competitive varieties are an integral part of IWM systems and should be considered when planning for weed control. Increasing seeding rates improves yield by outcompeting weeds and reduces the amount of weeds that set seed. [12]

Key issues:

- Good agronomy generally means a competitive crop
- A competitive crop greatly improves weed control by reducing weed biomass and seedset (Photo 3)
- Different crops and varieties compete with and suppress weeds differently
- High crop sowing rates reduce weed biomass and weed-seed production and may improve crop yield and grain quality. Optimising for yield and quality is advised
- Sow seed at optimum depth
- Fertiliser placement can improve crop growth, yield and competitive ability
- Many studies show a reduction in weeds with increased sowing rate and narrower rows
- Furrow-sowing or moisture-seeking techniques at sowing can help establish the crop before the weeds
- Sowing at the recommended time for the crop type and variety maximises crop competitive ability, which will reduce weed biomass and seedset
- When delaying sowing to allow for control of the first germination of weeds, choose the crop type and variety most suited to later sowing to minimise yield loss
- Sow problem weedy paddocks last to allow a good weed germination and subsequent kill prior to sowing

A summary table of some of the key research in Australia to assess the effect of increasing crop sowing rate in the presence of weeds can be found in IWM Section 4: Agronomy.

12 S Goss, R Wheeler (2015) Using crop competition for weed control in barley and wheat. GRDC Update Papers, 10 February 2015, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Using-crop-competition-for-weed-control-in-barley-and-wheat

MORE INFORMATION

GRDC (2014) Summer Fallow Weed Management Manual.

GRDC (2014) Summer fallow spraying. Northern, Southern and Western Regions. Fact sheet.

GRDC (2014) Weed control in wheel tracks. Northern, Southern and Western Regions. Fact sheet.

WeedSmart (2014) Diverting weed seed onto permanent tramlines. Video.

GRDC (2013) Compete with weeds—give your crop heaven and your weeds hell. GRDC Update Paper.

GRDC (2013) Landscape and weed influence on pest and beneficial insect populations. GRDC Update Paper.

GRDC (2011) Break crop benefits. Western Region. Fact sheet.

GRDC (2011) Time of sowing. Western Region. Fact sheet.

GIWA (2014) Aim for the narrowest possible row spacing WA. Research paper.

Photo 3: *No barley seed (buffer) sown except at beginning of the plot due to a seeding hiccup (left). Barley seed (buffer) sown to establish 120 plants per square metre (right).*

Source: Blakely Paynter

6.2.3 Crop type

Crops with herbicide-tolerance traits bred using conventional methods have been used in Australia for many years. They include imidazolinone-tolerant canola, wheat, maize, and barley (Clearfield®).

Herbicide-tolerant crops are tolerant to a herbicide that would normally cause severe damage. Thus, they offer the option of weed-control tactics from different herbicide MOA groups that would not normally be used in these crops.

Specific herbicide-tolerance crop-technology stewardship programs are a source of information on herbicide tolerance. More detailed information can be found at Clearfield® Stewardship Program.

Advantages of herbicide-tolerant crops:

- They provide additional crop choice, enabling use of alternative weed-management tactics.
- They can sometimes enable a crop type to be grown where herbicide residues may be present in the soil from a previous crop.
- They can reduce the total amount of herbicide used and/or weed-control costs.
- They provide another option to use some herbicides. This should always be used in an IWM program and within the guidelines for the relevant stewardship program for that technology.

Herbicide-resistance management guidelines for Australia for MOA groups can be downloaded from the CropLife Australia Limited website.

Summer weed control is important to conserve soil moisture and nitrogen (N) for the subsequent crop. Poor control of summer weeds can lead to blockages in seeding equipment and reduced soil water and N levels. Western Australian research has shown that there can significant yield loss when summer weeds are not controlled.

6.3 Key weeds in WA's cropping system

Annual ryegrass (*Lolium rigidum*)

Barley grass (*Hordeum* spp.)

Barnyard grasses (*Echinochloa* spp.)

MORE INFORMATION

Click on each weed for more information

Black bindweed (*Fallopia convolvulus*)

Bladder ketmia (*Hibiscus trionum*)

Brome grass (*Bromus* spp.)

Capeweed (*Arctotheca calendula*)

Doublegee (*Emex australis*)

Feathertop Rhodes grass (*Chloris virgata*)

Fleabane (*Conyza* spp.)

Fumitory (*Fumaria* spp.)

Indian hedge mustard (*Sisymbrium orientale*)

Liverseed grass (*Urochloa panicoides*)

Muskweed (*Myagrum perfoliatum*)

Paradoxa grass (*Phalaris paradoxa*)

Silver grass (*Vulpia* spp.)

Sweet summer grass (*Brachiaria eruciformis*)

Turnip weed (*Rapistrum rugosum*)

Wild oats (*Avena fatua* and *Avena ludoviciana*)

Wild radish (*Raphanus raphanistrum*)

Windmill grass (*Chloris truncata*)

Wire weed (*Polygonum aviculare* and *Polygonum arenastrum*) [13]

6.4 Stopping weed seedset

Risk-aware growers can implement strategies to reduce and avoid unnecessary introduction and spread of weeds.

Weed importation and spread can be impeded at several critical points, namely:

- sowing of the seed
- fencelines and non-cropped areas in cropping paddocks (e.g. water courses)
- machinery and vehicle usage
- stock feed and livestock movement
- in fields following floods and inundation.

A well-managed, on-farm hygiene strategy will address each of these elements.

6.4.1 Seedset control tactics

Seedset control tactics are particularly effective in low-level weed populations and include:

- spray-topping with selective and non-selective herbicides
- wick wiping
- windrowing and crop desiccation
- techniques such as hand-roguing, spot-spraying, green and brown manuring, hay or silage production and grazing

Harvest weed-seed control tactics include narrow windrow burning, chaff-lining and chaff carts.

13 GRDC (2014) Section 8. Profile of common weeds of cropping. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/common-weeds-of-cropping

In-crop management of weed seedset is used to minimise the replenishment of seedbanks and/or reduce grain contamination. This is achieved by intercepting the seed production of weeds that have escaped, survived or emerged after application of weed-management tactics earlier in the cropping season.

Controlling weed seedset contrasts with early in-crop weed management tactics, which aim to maintain or maximise crop yield by reducing weed competition. There is minimal grain-yield benefit in the current crop from seedset control tactics, because most weed competition occurs earlier, during the vegetative stages of the crop. For this reason, seedset control tactics should always be used with other tactics. [14]

6.4.2 Selective spray-topping

Selective spray-topping is the application of a post-emergent, selective herbicide to weeds at reproductive growth stages to prevent seedset. The technique is aimed at weed seedbank management (i.e. reducing additions to the weed seedbank) but with minimal impact on the crop.

Selective spray-topping largely targets broadleaf weeds (especially *Brassica* weeds). The tactic should not be confused with pasture spray-topping, which occurs in a pasture phase, involves heavy grazing, uses a non-selective herbicide, and largely targets grass weeds.

The strategy can be used to control 'escapes', as a late post-emergent salvage treatment, or for managing herbicide resistance.

The rapid spread of Group B resistance in *Brassica* weeds and Group A and Z resistance in wild oat (*Avena* spp.), along with the uncertain supply of the herbicide Mataven® (flamprop-M-methyl, for wild oats), has significantly reduced the potential application of this tactic. [15]

6.4.3 Crop desiccation and windrowing

Crop desiccation with a non-selective herbicide and windrowing (also called 'swathing') are harvest aids. If conducted when weeds are green and growing, windrowing and crop desiccation can significantly reduce weed seedset.

These tactics are conducted at or just after crop physiological maturity. The greatest levels of weed control will occur if the crop matures before the weeds, so short-season cultivars are best suited.

Windrowing and desiccation can:

- encourage even ripening of crops
- increase harvest speed and efficiency
- minimise yield loss from shattering or lodging
- enhance seed quality
- overcome harvest problems caused by late winter or early summer weed growth
- minimise weather damage during harvest by increasing the speed of drying while protecting the crop in the windrow
- improve the yield of following crops by halting water use by the current crop (crops can continue to use soil water when past physiological maturity)

Any weed regrowth must be controlled to minimise seed production.

Harvest withholding periods must be known before using herbicides for crop desiccation. [16]

14 GRDC (2014) Section 5. Stopping weed seed set. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

15 GRDC (2014) Section 5. Stopping weed seed set. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

16 GRDC (2014) Section 5. Stopping weed seed set. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

MORE INFORMATION

IWM Section 6: Stopping weed seed set

VIDEO

WeedSmart: Control harvest weed seed set with windrows and crop topping.

A minor use permit has recently been granted by the APVMA for pre-harvest desiccation and spray topping of weeds in feed barley. This practice is not allowed in varieties intended to be delivered as malt or food grade. Malt and food varieties that are desiccated with glyphosate must be downgraded to feed barley. There are specific requirements for this practice and it is essential that growers read and follow the label or APVMA permit before undertaking this practice (Permit number PER82594).

6.4.4 Manuring, mulching and hay freezing

Sacrificing a portion of the crop as a way to manage weed patches that have escaped control can be an effective management tool.

Crops and pastures can be returned to the soil by burial, mulching or chemical desiccation with the key aims of reducing weed seedbanks, improving soil fertility and maintaining soil organic matter.

Green manuring incorporates green plant residue into the soil with a cultivation implement, and brown manuring uses non-selective herbicides (Photo 4).

Mulching is similar to brown manuring but involves mowing or slashing the crop or pasture and leaving the residue laying on the soil surface.

Hay freezing is similar to brown manuring with the additional aim of creating standing hay. In this case, herbicide is applied earlier than if the crop were to be mown for conventional haymaking.

If performed before weed seedset and all weed regrowth is controlled, reductions in weed seedset of >95% are possible. [17] However, this is very expensive as it means forgoing harvest of this area of barley.

Photo 4: *Hay cutting (left) and brown manuring (right)—two options to stop weed seedset.*

Source: A. Douglas

6.5 Herbicide resistance

Herbicide resistance is an increasing threat across Australia's grain regions for both growers and agronomists. For most herbicide MOAs, more than one resistance mechanism can provide resistance, and within each target site, a number of amino acid modifications provide resistance. This means that resistance mechanisms can vary widely between populations; however, some patterns are common. Although

17 GRDC (2014) Section 5. Stopping weed seed set. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

some broad predictions can be made, a herbicide test is the only sure way of knowing which alternative herbicide will be effective on a resistant population. [18]

Western Australian growers are leaders in the adoption of harvest weed seed control (HWSC) practices which, when combined with other control measures, play a crucial role in reducing weed populations and weed seed banks, minimising the impact of herbicide resistance.

The total cost of using HWSC practices is estimated at $17 million, with $13 million of this spent in the Western Region. [19]

Testing services

For testing of suspected resistant samples, contact:

Charles Sturt University Herbicide Resistance Testing
School of Agricultural and Wine Sciences
Charles Sturt University
Locked Bag 588
Wagga Wagga, NSW 2678
02 6933 4001
http://www.csu.edu.au/weedresearchgroup/herbicide-resistance

Plant Science Consulting
22 Linley Ave
Prospect, SA 5082
0400 664 460
info@plantscienceconsulting.com.au, www.plantscienceconsulting.com

Weed out herbicide resistance

Act now to stop weeds from setting seed (see the following section, Managing the weed seedbank):

- Destroy or capture weed seeds
- Understand the biology of the weeds present
- Remember that every successful WeedSmart practice can reduce the weed seedbank over time
- Be strategic and committed—herbicide-resistance management is not a one-year decision
- Research and plan your WeedSmart strategy
- You may have to sacrifice yield in the short term to manage resistance—be proactive
- Find out what other growers are doing, and visit www.weedsmart.org.au

Capture weed seeds at harvest. Options to consider are:

- Tow a chaff cart behind the header
- Check out the Harrington Seed Destructor
- Create and burn narrow windrows
- Produce hay where suitable
- Funnel seed onto tramlines in controlled-traffic farming systems
- Crop-top where suitable
- Use a green or brown manure crop to achieve 100% weed control and build soil N levels

Rotate crops and herbicide MOAs:

- Look for opportunities within crop rotations for weed control

18 C Preston (2014) The mechanisms of herbicide resistance. GRDC Update Papers, 5 March 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/The-mechanisms-of-herbicide-resistance

19 RS Llewellyn and D Ronning et al. (2016) Impact of Weeds on Australian Grain Production. Report for GRDC. CSIRO Australia, https://grdc.com.au/Resources/Publications/2016/03/Impact-of-weeds-on-Australian-grain-production

- Understand that repeated application of effective herbicides with the same MOA is the single greatest risk factor for evolution of herbicide resistance
- Protect the existing herbicide resource
- Remember that the discovery of new, effective herbicides is rare
- Acknowledge that there is no quick chemical fix on the horizon
- Use break crops where suitable
- Growers in high-rainfall zones should plan carefully to reduce weed populations in the pasture phase prior to returning to cropping

Test for resistance to establish a clear picture of paddock-by-paddock weed status:

- Sample weed seeds prior to harvest for resistance testing to determine effective herbicide options
- Use the 'Quick Test' option to test emerged ryegrass plants after sowing to determine effective herbicide options before applying in-crop selective herbicides
- Visit the WeedSmart website, http://www.weedsmart.org.au/ or www.ahri.uwa.edu.au for more information on herbicide-resistance survey results.

Aim for 100% weed control and monitor every spray event:

- Stop resistant weeds from returning into the seed bank
- Focus on management of survivors in fallows
- Where herbicide failures occur, do not let the weeds seed. Consider cutting for hay or silage, fallowing or brown manuring the paddock
- Patch-spray areas of resistant weeds only if appropriate
- Never cut the on-label herbicide rate, and carefully manage spray drift and residues

Do not automatically reach for glyphosate:

- Use a diversified approach to weed management
- Consider post-emergent herbicides where suitable
- Consider strategic tillage

Use best management practice in spray application. Consult GRDC Fact Sheets, available at www.grdc.com.au.

- Consider selective weed sprayers such as WeedSeeker® or WEEDit®

Plant clean seed into clean paddocks with clean borders:

- It is easier to control weeds before the crop is planted
- Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds
- A recent Australian Herbicide Resistance Initiative (AHRI) survey showed that 73% of grower-saved crop seed was contaminated with weed seed
- The density, diversity and fecundity of weeds are generally greatest along paddock borders and areas such as roadsides, channel banks and fence lines

Use the double-knock technique:

- Double-knock is the use of any combination of weed control that involves two sequential strategies; the second application is designed to control survivors of the first method of control used
- Access GRDC research results at www.grdc.com.au

Employ crop competitiveness to combat weeds:

- Consider narrow row spacing and seeding rates
- Consider twin-row seeding points

VIDEO

Strategic Tillage

- Use high-density pastures as a rotation option.
- Consider brown manure crops
- Rethink bare fallows [20]

6.6 Managing the weed seedbank

The weed seedbank is defined as the mature seeds that exist in the soil. At any given time, the soil seedbank contains viable weed seeds produced in several previous years (the seedbank). These seeds (of different ages) will either be able to germinate when the conditions are favourable (suitable temperature, adequate water and enough oxygen) or be dormant.

When new seed is prevented from entering the seedbank, persistence can be determined by measuring the time taken for the number of weed seeds in the soil to diminish to negligible levels. This will vary with weed species because of the differing levels and types of dormancy.

There are two ways to diminish the seedbank:

- Weed seed germination and subsequent seedling emergence. Factors including light, soil conditions such as temperature and moisture, the soil's gaseous environment and nutrient status all affect the seed's dormancy and ability to germinate. Tillage can affect seed germination by redistributing the seed to a different profile in terms of moisture, temperature and so on, or changing the amount of available light. Autumn tickle stimulates germination of some weed species by placing seed in a better physical position in the soil. (Note: this is not applicable to surface-germinating weeds.) A well-timed autumn tickle will promote earlier and more uniform germination of some weed species for subsequent control. Tickling often needs to be used in conjunction with delayed sowing.
- Seed loss other than germination. Most seeds fail to emerge as seedlings. Some are buried at depths too great to permit emergence and a large fraction simply lose viability over time and die of old age. After long-term reduced tillage or no-tillage, most weed seed is at, or close to, the soil surface.

Some weed seeds may also be eaten or attacked by pathogens. A study in the WA wheatbelt found that 81% of the original annual ryegrass seed and 46% of wild radish seed had been removed by ants (seed predation).

Natural mortality rates of weed seed are far higher in no-till systems where weed seed is left on the soil surface than in systems where weed seed is mixed in the top few centimetres of soil. Burying some types of weed seeds can increase seedbank dormancy and slow the rate at which the seedbank is depleted. [21]

6.6.1 Burning residues

Fire can be used to kill weed seeds on the soil surface if there is sufficient fuel load and the fire is hot enough (Photo 5). Burning over summer poses an unduly high fire hazard and is illegal in most regions without a permit from the local authority. An autumn burn often poses a lower fire hazard and leaves crop residue in place to protect soil from wind and water erosion for a longer period. Maintaining stubble for longer also benefits soil water capture and retention, provided summer weed growth is controlled.

To obtain high levels of control of weeds such as annual ryegrass and wild radish, a hot fire is needed. This is obtained by windrow burning, where crop residues are concentrated with weed seed in a narrow windrow and then burnt. [22]

20 WeedSmart, http://www.weedsmart.org.au

21 GRDC (2014) Section 5. Managing the weed seed bank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

22 GRDC (2014) Section 5. Managing the weed seed bank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

Photo 5: *Chaff dumps can be burnt in autumn, killing a high proportion of seeds present.*

Source: A. Storrie

6.6.2 Encouraging insect predation of seed

The contribution that insects make to seedbank reduction is often overlooked, despite weed seeds comprising a major component of many insect diets (Photo 6). This predation of seed contributes to 'natural mortality' and partly explains why less seed germinates than is produced.

Photo 6: *Grass seeds collected by ants.*

Source: A. Storrie

6.6.3 Autumn tickle

Autumn tickling (also referred to as an 'autumn scratch' or shallow cultivation) stimulates germination of weed seeds by improving seed contact with moist soil. Controlling these germinating weeds depletes the weed seed reserves and such a process will ultimately deplete weed seed reserves. Autumn tickling can reduce the efficacy of pre-emergent herbicides like trifluralin which work better when applied near the ryegrass seed.

An autumn tickle can be conducted with a range of equipment, including tined implements, skim ploughs, heavy harrows, pinwheel (stubble) rakes, dump rakes and disc chains.

Tickling can increase the germination of some weed species but has little effect on others. Tickling needs to be used in conjunction with delayed sowing to allow time for weeds to emerge and to be controlled prior to seeding. [23]

6.6.4 Delayed sowing

Delayed sowing (seeding) is the technique of planting the crop beyond the optimum time for yield in order to maximise weed emergence and control prior to sowing. Weeds that emerge in response to the break in season can then be killed by using a knockdown herbicide or cultivation prior to crop sowing (Photo 7).

This tactic is most commonly employed for paddocks which are known to have high weed burdens. Paddocks with low weed burdens are given priority in the sowing schedule, leaving weedy paddocks until later. This allows sufficient delay for the tactic to be beneficial on the problem paddock without interrupting the whole-farm sowing operation.

Choosing a crop or cultivar with a later optimum sowing time can reduce yield impact of a later sowing date. [24]

However, recent studies have shown the general impact of delayed sowing is to decrease early biomass, plant height, lodging risk, and grain yield, whilst increasing screenings, grain protein concentration and grain brightness. Delayed sowing can increase the risk of delivering feed grade barley, primarily due to high screenings and high grain protein. [25]

Photo 7: *Delayed sowing allows use of knockdown herbicides or cultivation to control small weeds prior to sowing, reducing the pressure on selective in-crop herbicides.* [26]

Source: D. Holding

23 GRDC (2014) Section 5. Managing the weed seed bank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

24 GRDC (2014) Section 5. Managing the weed seed bank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

25 B Paynter, A Hills and R Mali (2016) How much is the seed rate (changing from 50 to 400 plants/m^2) response of barley influenced by date of seeding? GRDC Western Research Updates, 29 Feb–01 Mar 2016. http://www.giwa.org.au/2016researchupdates

26 GRDC (2014) Section 5. Managing the weed seed bank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-5-managing-the-weed-seedbank

6.7 Managing weed seedlings

Killing weeds with cultivation has been the focus of weed management since agriculture was first developed. Since the release of glyphosate and Group A and B herbicides in the early 1980s, herbicides have been the primary tool for controlling weeds because they are cost-effective, do not disturb soil and crop residue, have high levels of control and are easy to use. However, this approach to controlling weeds has led to the development of herbicide resistance. Despite herbicide resistance, herbicides remain an important tool but require support from a range of non-herbicide tactics to remain effective.

Tactics that assist include fallow, pre-sowing and inter-row cultivation, double-knock, alternate pre- and post-emergent herbicides, roguing individual plants, weed-detector spraying and harvest weed-seed control. Used alone, none of the currently available cultural techniques provide an adequate level of weed control. However, when used in carefully planned combinations, extremely effective control can be achieved. [27]

MORE INFORMATION

IWM Section 5: Tactics

6.7.1 Killing weeds with tillage

Cultivation can kill many weeds, including herbicide-resistant and hard-to-kill populations. Cultivation is useful as a 'one-off' tactic in reduced-tillage or no-till operations. Well-timed cultivation in a no-till system can give a range of benefits with manageable reduction on conservation farming goals. [28]

Planned cultivation can also be used as a non-herbicide component of a double-knock system.

Benefits

Well-timed cultivation in a drying soil effectively kills weeds. Cultivation destroys weeds in a number of ways, including:

- plant burial
- seed burial, thus reducing the ability to germinate if sufficiently deep
- severing roots
- plant desiccation, where plants are left on the soil surface to die
- breaking seed dormancy or seed being placed in a more favourable environment to encourage germination for subsequent control

In preparing a seedbed, cultivation provides a weed-free environment for the emerging crop and can improve soil surface conditions for even application of pre-emergent herbicides.

Cultivation can control weeds in situations where herbicides are ineffective or not an option.

Pre-sowing cultivation or full-disturbance cultivation at sowing reduces reliance on knockdown herbicides and therefore the likelihood of weed populations developing herbicide resistance.

Shallow cultivation to incorporate pre-emergent herbicides reduces loss due to volatilisation and photodegradation.

Whole-farm benefits

Weed management can have an additional benefit where cultivation is used for:

- incorporating soil ameliorants (e.g. lime or gypsum)

27 GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

28 Y Dang et al. (2013) Tillage impact in long term no-till. GRDC Update Papers, 27 Feb. 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Tillage-impact-in-long-term-no-till

- overcoming stratification of non-mobile nutrients such as phosphorus or redistribution of potassium that has been concentrated in surface zones after years of no-till
- breaking up a hard pan or subsoil restriction

Issues with tillage

The term 'strategic tillage' has been widely quoted. In many instances when tillage is used to combat herbicide-resistant weeds, the timing of tillage is driven more by weed escapes than by good planning:

- Using tillage at the start of a summer fallow will degrade soil cover, leaving the soil more exposed to wind and water erosion and evaporation over the summer period
- In wet soil conditions, the percentage weed kill delivered by tillage is often poor due to replanting of weeds back into moist soil
- Compaction can occur, particularly in wet soils
- Tillage speeds breakdown of stubble and reduces protection from water and wind erosion
- In the weeks prior to sowing, tillage can lead to a loss of soil water needed for crop establishment
- In cracking clay soils, tillage can close surface cracks and reduce the soil's ability to accept high-intensity, summer-storm rainfall, with ensuing runoff and soil loss
- Tillage will bury weed seeds, which may prolong seedbank dormancy in many weed species and can reduce efficacy of some pre-emergent herbicides used at sowing
- Tillage often costs more, requires greater capital investment and more labour, and is slower than spraying

Tillage works best in dry or drying soil environments. Weeds are easier to kill when their root systems are small. Larger plants may need a more aggressive implement and/or multiple passes. [29]

MORE INFORMATION

GRDC (2014) Strategic tillage. Fact sheet.

Further information on registered chemicals can be obtained from APVMA and CropLife Australia.

6.7.2 Killing weeds with herbicides

The rapid development of resistance to glyphosate in several weeds has placed increased reliance on in-crop weed management. Many selective herbicides already have resistance issues; therefore, an increase in reliance on pre-emergent herbicides is forecast while these remain effective.

The last significant new MOA groups released into the Australian herbicide market were Group B, when chlorsulfuron was launched in 1982, and Group H in 2001. No new post-emergent herbicides appear anywhere near commercialisation, so it is clear that the supply of new chemistries is limited.

The only new MOAs on the horizon (and they are not great in number) are all pre-emergent chemistries. Hence, the need to look after what is available for as long as possible. [30]

Knockdown (non-selective) herbicides for fallow and pre-sowing control

Knockdown herbicides are key tools to enable no-till fallows to be managed economically and efficiently.

Knockdown herbicides also represent a key component of other weed-management tactics, including:

29 GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

30 GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

MORE INFORMATION

[Integrated Weed Management Hub]

[GRDC (2014) Summer fallow weed management manual.]

[GRDC (2014) Spray equipment, Northern, Southern and Western Regions. Fact sheet.]

[GRDC (2014) Spray height control, Northern, Southern and Western Regions. Fact sheet.]

[GRDC (2014) Spray water quality, Northern, Southern and Western Regions. Fact sheet.]

- controlling weeds before sowing (see delayed sowing and agronomy in IWM Section 3)
- herbicide-tolerant crops (agronomy)
- controlling weeds in fallow (agronomy)
- crop-topping
- use of wiper methods (see tactic 3.1 in IWM Section 4)
- crop desiccation (see tactic 3.1)
- pasture spray-topping (see tactic 3.2)
- brown manuring and hay freezing (see tactic 3.4).

Since its release in the late 1970s, glyphosate has become the most widely used herbicide worldwide. Prior to this, paraquat was more commonly used.

In unselected weed populations, genes carrying resistance to glyphosate are rare, and selection for 15+ years is required before the frequency of resistant individuals is likely to lead to a spray failure.

The Australian Glyphosate Sustainability Working Group provides up-to-date information on glyphosate and paraquat resistance.

With widespread use over a prolonged period and often few, if any, other measures taken to control weed escapes, populations of weeds resistant to glyphosate have increased exponentially. This increase is forecast to continue.

In winter-crop no-till rotations, the selection pressure for resistance to glyphosate is placed more on summer weeds. Glyphosate resistance has developed in multiple grass weeds, as well as fleabane. No-tillage has enabled the wheatbelt to expand into lower rainfall rangeland country because it has enabled far better management and storage of limited rainfall. Increasingly, however, widespread resistance to glyphosate threatens the base technology of many current cropping systems.

With widespread use of herbicides comes increased potential for spray drift. Weather conditions, droplet size and proximity to adjoining crops are critical issues. [31]

Please Note: The use of approved herbicides for the purposes of weed control must be carried out in accordance with herbicide labelling instructions, which require grain growers to follow written label directions. Barley Australia wishes to make clear that glyphosate is not registered for late season application on malt or food grade barley in Australia and does not condone it usage in this way. [32]

Double-knockdown or double-knock

Double-knock is the sequential application of two different weed-control tactics where the second tactic controls any survivors from the first tactic.

An example in common use is the sequential application of glyphosate (Group M) followed by paraquat or diquat (Group L) at an interval of 1–14 days. Each herbicide must be applied at a rate sufficient to control weeds if it were used alone. The second herbicide is applied to control any survivors from the first herbicide application. Control of weeds that germinate during the interval between the two applications of herbicide is an incidental benefit.

Other double-knock strategies include following a herbicide with burning or grazing, or seed capture and removal or burning. Increased levels of crop competition can also provide a partial double-knock to reduce the number of weed seeds set after application of an in-crop herbicide.

Double-knock strategies delay the onset of herbicide resistance; however, modelling shows that if many years of selection take place in which survivors of glyphosate applications are allowed to set seed before double-knock strategies are used,

31 GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

32 Barley Australia (2016) Late Crop Herbicide Application (crop topping) on Barley, http://www.barleyaustralia.com.au/media-releases

the benefit of double-knock as a delaying strategy for the onset of resistance to glyphosate is greatly diminished. [33]

Using a double-knock strategy reduces the number of glyphosate-resistant weeds to be controlled in-crop and improves the general level of weed control obtained.

Some key grass and broadleaved weeds can only be reliably controlled using double-knockdown sprays.

Populations of weeds that have developed resistance to glyphosate:

- annual ryegrass (*Lolium rigidum*)
- awnless barnyard grass (*Echinochloa cruss-galli*)
- great brome grass (*Bromus* spp.)
- red brome (*Bromus rubens)*
- liverseed grass (*Urochloa panicoides*)
- windmill grass (*Chloris truncata*)
- flaxleaf fleabane (*Conyza bonariensis*)
- wild radish (*Raphanus raphanistrum*)
- sowthistle (*Sonchus* spp.)

Weeds that are naturally tolerant of glyphosate:

- feathertop Rhodes grass (*Chloris virgata*)

Note there are residual or re-crop issues for following crops when using Group A herbicides in fallow.

Key issues for double-knock

Where glyphosate and paraquat are appropriate products to use, glyphosate should be applied first followed by paraquat or paraquat–diquat.

The ideal time between applications will vary with the main target weed species.

Almost all annual species benefit from ≥1 day between applications. In some species, longer delays of one to two weeks are beneficial, but delaying too long can lead to regrowth of weeds and poorer results. Research undertaken by AHARI shows that one to 10 days is ideal for ryegrass.

Apply the first herbicide when the weeds are most likely to be killed; that is, when small and actively growing.

Maximum control of annual ryegrass results from an application of herbicide at the 3–4-leaf stage. Annual ryegrass sprayed at the 0–1-leaf stage can regrow from seed reserves. Later application, when the annual ryegrass is tillering, risks incomplete control because little translocation takes place within the plant.

When applying contact herbicides or Group A herbicides, increase spray carrier volume and avoid very coarse droplet sizes, because excellent spray coverage is needed for success. Seasonal conditions and spraying capacity will influence the scale of on-farm implementation.

Target this tactic to paddocks with the highest weed populations, because these are at higher risk of selection for resistance.

Use of a double-knock strategy on a percentage of land each year will add logistical stress to spray operations so needs to be planned for. [34]

33 DT Thornby, SR Walker, JPM Whish (2008) Modeling to estimate glyphosate resistance risk in barnyard grass in the northern Australian grain region. *Proceedings of the 16th Australian Weeds Conference*, http://www.caws.org.au/awc/2008/awc200815131.pdf

34 GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

Pre-emergent herbicides

Pre-emergent herbicides control weeds at the early stages of the life cycle, between radicle (root and shoot) emergence from the seed and seedling leaf emergence through the soil.

Some pre-emergent herbicides also have post-emergent activity through leaf absorption and they can be applied to newly emerging weeds.

The residual activity of a pre-emergent herbicide controls the first few flushes of germinating weeds (cohorts) while the crop is too small to compete. As a result, pre-emergent herbicides are often excellent at protecting the crop from early weed competition.

Factors to consider when using pre-emergent herbicides:

- **Weed species and density.** Knowing which weeds to expect is critical. Pre-emergent herbicides are particularly useful at stopping early weed competition, especially if high weed densities are expected.
- **Crop or pasture type.** What is registered, how competitive is the crop and which post-emergent options exist?
- **Soil condition.** Cloddy soil surfaces, large amounts of stubble or an excess of ash from stubble burning can affect the performance of some pre-emergent herbicides. The more mobile herbicides such as sulfonylureas and imidazolinones may not need mechanical incorporation, because they move into the topsoil with water. Some herbicides need incorporation or coverage to prevent UV losses (e.g. atrazine) or volatilisation (e.g. trifluralin).
- **Rotation of crop or pasture species.** All pre-emergent herbicides persist in the soil to some degree. Some post-emergent herbicides may also persist in the soil. Consequently, herbicides may carry over into the next cropping period. The time between spraying and safely sowing a specific crop or pasture without residual herbicide effects (the plant-back period) varies, depending on the herbicide, environmental conditions and soil type.

The following influence the fate of herbicides in the soil (Table 2):

- herbicide adsorption and solubility
- herbicide mechanism of breakdown (i.e. chemical or microbial)
- soil texture
- soil pH (for some herbicides)
- organic matter
- previous herbicide use
- soil moisture
- initial application rate
- soil temperature
- volatilisation
- photodegradation

Table 2: *Soil attributes that contribute to herbicide availability*

Higher herbicide availability	Lower herbicide availability
Sandy soils	Clay soils
Low organic matter	High organic matter
High pH (triazines and sulfonyl ureas)	Low pH
Low pH (imidazolinones)	High pH
Wet conditions	Dry conditions

MORE INFORMATION

IWM Section 5: Tactics

GRDC (2014) Pre-emergent herbicide use, Northern, Southern and Western Region. Fact sheet.

When using pre-emergent herbicides, consider how the herbicide kills weeds, how it gets into the weed zone and where it will be when weeds are germinating (Table 3). Typically, situations that reduce availability will require higher application rates to achieve equivalent control. Properties that reduce availability also tend to increase the length of herbicide persistence in the soil, thus increasing rotational crop constraints.

A pre-emergent herbicide that is sitting on a dry soil surface at the time of weed emergence is unlikely to have sufficient soil moisture for uptake by the weed or sufficient contact with the emerging weeds to kill them. This might occur if the herbicide was applied immediately post-sowing while weeds were already germinating and if there was no rain or mechanical incorporation to take the herbicide into the germination zone, where it can be taken up by the young weeds. Weed escapes in such situations are likely.

Crop safety is also an important issue when using pre-emergent herbicides. Crop tolerance of several pre-emergent herbicides (i.e. trifluralin, pyroxasulfone, prosulfocarb) is often related to spatial separation of the young crop from the herbicide. This, in turn, is related to the solubility and potential movement in the soil of the herbicide, the crop establishment process, the level of soil displacement over the crop row, follow-up rainfall and the physical nature of the seed furrow. [35]

Table 3: *Positive and negative aspects of using pre-emergent herbicides*

Positive	Negative
Relatively inexpensive	Strongly dependent on soil moisture
Optimises crop yield through control of early weed germinations	Because weeds are not yet visible, must have paddock history/knowledge of previous weeds/weed seedbank
Different modes of action to most post-emergent herbicides	Plant-back periods limit crop rotation
Timing of operation: generally have a wide window of opportunity for application options	Crop damage if sown too shallow or excessive quantities of herbicide move into root-zone
Best option for some crops where limited post-emergent options exist	Seedbed preparation: soil may need cultivation and herbicide may need incorporation, which can lead to erosion, soil structural decline and loss of sowing moisture
Effective on some weeds that are hard to control with post-emergent herbicides (e.g. wireweed and black bindweed)	Not suitable when dense plant residues or cloddy soils are present
Extended period of control of multiple cohorts; good for weeds with multiple germination times	Varying soil types and soil moisture across paddock can be reflected in variable results

Selective post-emergent herbicides

Selective post-emergent herbicides control emerged weeds in the crop or pasture.

The first selective post-emergent developed was a Group I herbicide, 2,4-D (released ~1945). Group A and B herbicides were released in the 1980s.

Selective post-emergent herbicides belong to MOA Groups A (e.g. diclofop), B (e.g. metsulfuron), C (e.g. diuron), F (e.g. diflufenican), G (e.g. carfentrazone), I (e.g. 2,4-D, dicamba, picloram), J (e.g. flupropanate) and R (e.g. asulam).

Many new selective post-emergent herbicides have been released in recent years; however, all of them have been from known MOA groups. No new post-emergent

35 Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

herbicides from new MOA groups are likely to be released in the near future, although new groups may have been identified by researchers.

Selective post-emergent herbicides give high levels of control (often >98%) when applied under recommended conditions on susceptible populations. When used early in crop development, at recommended rates and timings, selective post-emergent herbicides also result in optimum yield with potential for significant economic returns.

Early use on small susceptible weeds improves control levels achieved and removes weeds before significant crop yield loss occurs.

In addition to post-emergent activity, some post-emergent herbicides have pre-emergent activity on subsequent weed germinations. This is particularly the case with some Group B, C, F and I herbicides.

When choosing a selective post-emergent herbicide for a particular situation, consider the following factors:

- target weed species and growth stage
- herbicide resistance status of target weeds
- crop safety (variety, environmental conditions, effect of previously applied herbicide on crop)
- grazing and harvest withholding periods and plant-back periods
- cost
- spray-drift risk
- mix partners

Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.

Crops that are usually tolerant can be damaged when stressed by waterlogging, frost or dry conditions because they cannot produce sufficient levels of the enzymes that normally break the herbicide down; for example, when sulfonylureas are applied to cold and waterlogged crops, high levels of crop impact are seen. Group A herbicides often fail to kill weeds if applied too soon after a severe cold stress (frost).

When using selective post-emergent herbicides, it is important to use the correct application technique. Particular attention should be paid to:

- Equipment. Nozzles, pressure, droplet size, mixing in the tank, boom height and groundspeed should be set to maximise the efficiency of herbicide application to the target
- Meteorological conditions. Suitable conditions are indicated by Delta T (ideally <8°C) when air movement is neither excessively windy nor still. (Delta T is an indication of evaporation rate and droplet lifetime and is calculated by subtracting the wet bulb temperature from the dry bulb temperature.)

Spraying should not be conducted in inversion conditions and ideally should be done when temperatures are <28°C.

To get the best performance from the herbicide being applied, use the adjuvant recommended on the herbicide label. Because plants have different leaf surfaces, an adjuvant may be needed to assist with herbicide uptake and leaf coverage. Some adjuvants can also increase performance by lowering the pH, water hardness, compatibility, rain-fastness or drift.

Selective post-emergent herbicides applied early and used as a stand-alone tactic often have little impact on weed seedbanks.

Early post-emergent herbicide use is aimed at maximising yield by removing weed competition at crop-establishment stages. Any weed that germinates after or survives this application will set seed that will return to the seedbank, thus maintaining weed seedbank numbers and ensuring continuation of the weed problem.

MORE INFORMATION

GRDC (2012) Adjuvants—oils, surfactants and other additives for farm chemicals.

To drive the weed seedbank down over time, use later season seedbank-management tactics in association with early post-emergent tactics (Table 4). Seedbank capture and management tactics work similarly to help drive the weed seedbank down.

Table 4: *Effect of annual applications of different herbicide treatments on wild oat seedbank numbers after five years*

Herbicide treatment	Percentage change in wild oat numbers over 5 years
Pre-emergent alone	+15
Post-emergent alone	–40
Post-emergent + selective spray topping	–96

Source: Cook 1998

The effectiveness of selective post-emergent herbicides is influenced by a range of plant and environmental factors.

Inactivation of herbicides can occur from:

- leaf and cuticle structure
- dust particles
- washing product off the leaf due to rainfall or dew [36]

6.7.3 Spot-spraying, chipping, hand-roguing and wiper technologies

When weed numbers are low or when still contained in patches, hand-weeding, spot-spraying and other methods, including selective crop destruction, can be used to stop weed seedset and seedbank replenishment. This is especially useful for controlling a low number of surviving wild radish after previous herbicide treatments have been applied, to prevent seeds from resistant plants entering the seed bank.

Wiper technologies are useful when there is a height differential between the crop and weeds to allow a weed wiper to apply concentrated herbicide to the weed while avoiding contact with the crop plants.

Where new weed infestations occur in low numbers, eradication may be possible. In such situations, more intensive tactics to remove weeds can be used in addition to ongoing management tactics that aim to minimise weed impact.

Some key points:

- Stay vigilant for new or isolated weeds
- Be prepared to hand-pull weeds
- Keep a rubbish bag handy for weeds that already have seeds developed
- Correctly identify new weeds and appropriate control measures
- Manage and isolate outbreaks and hot spots
- Stop weed seedset
- Plan follow-up observation and management
- Mark isolated weed patches by GPS and diarise to check for later germinations [37]

MORE INFORMATION

Tactic 2.4 of IWM Section 5: Tactics

36 GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

37 GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

6.8 Harvest weed-seed control

Harvest weed seed control provides the opportunity to more effectively manage weed populations and move away from the reliance on herbicidal weed control. The consequence of this is that growers regain flexibility in the overall management of their cropping program. Growers in WA have driven the development of several systems now available that effectively reduce inputs of annual ryegrass, wild radish, wild oats and brome grass into the seed-bank. The adoption of these systems has been critical for the continuation of intensive cropping systems. Examples of harvest weed seed control are:

- chaff carts
- baling
- windrow burning
- chaff grinding (Harrington Seed Destructor - HSD) [38]

Targeting weed seeds at harvest is a pre-emptive action against problematic populations of annual weeds. The most damaging crop weeds—annual ryegrass, wild radish, wild oats and brome grass—are all capable of establishing large, persistent seedbanks. If annual weeds are allowed to produce seed that enters the seedbank, the cropping system will inevitably be unsustainable.

Fortunately, seedbank decline is rapid for these weed species, with annual seed losses of 60–80%. Without inputs, a very large seedbank (>1000 seed/m^2) can therefore be reduced to a very modest one (<100 seed/m^2) in just 4 years. A small seedbank of weeds allows easier and more effective weed control with a reduced risk of development of herbicide resistance. Effective weed management in productive cropping systems is thus reliant on preventing viable seed from entering the seedbank. Several systems developed over the past 3 decades target the weed-seed-bearing chaff fraction during harvest. [39]

For information on harvest weed-seed control and its application for the western grains region, see Section 12: Harvest.

VIDEO

Harvest Weed Seed Control (Cereal Crops)

6.9 Other non-chemical weed control

Crop rotation can be an effective means of managing a spectrum of weeds that result from continuous wheat cropping. Barley is a more vigorous competitor of weeds than wheat and it may be a suitable option for weed suppression. Increased planting rates and narrow rows may also help where the weed load has not developed to a serious level. [40]

The use of rotations that include both broadleaf and cereal crops may allow an increased range of chemicals—say three to five MOAs. Grazing and/or cultivation are alternative, non-chemical options.

Strategic cultivation can provide control for 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.

6.9.1 Biological control

Biological control for the management of weeds uses the weed's natural enemies (biological control agents). These include herbivores, such as insects and sheep, where there is direct consumption of the weed. Natural enemies also include microorganisms such as bacteria, fungi and viruses, which can cause disease,

38 GRDC (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012

39 M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012

40 DAF Qld (2012) Wheat: planting information. Department of Agriculture and Fisheries, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/planting-information

GRDC FACT SHEETS

In-crop herbicide use (Northern, Southern and Western Regions)

Practical tips for spraying (Northern, Southern and Western Regions)

Pre-harvest herbicide use (Northern, Southern and Western Regions)

Pre-season sprayer checks (Northern, Southern and Western Regions)

Summer fallow spraying (Northern, Southern and Western Regions)

Weed control in wheel tracks (Northern, Southern and Western Regions)

GRDC UPDATE PAPERS

Achieving good pre-emergent spray results

Getting the right mix

New technology for improved herbicide use efficiency

Seeding systems and pre-emergence herbicides

reduce weed vigour and competitiveness relative to the crop, and decay the weed seed in the seedbank. Other plants can also be included here, where they release substances that suppress weed growth—this is known as allelopathy. [41]

Most weeds are susceptible to grazing. Weed control is achieved through reduction in seedset and competitive ability of the weed. The impact is optimised when the timing of the grazing occurs early in the life cycle of the weed. [42]

6.10 Strategies to stop the spread of weeds

6.10.1 Sow weed-free seed

Weed seed is regularly spread around and between farms as a contaminant of sowing seed. Seed for sowing is commonly grower-saved and can be contaminated with weed seeds, frequently at very high levels. Various 'seed-box' surveys show that less than a quarter of farmers surveyed sow weed-free seed. On average, ungraded seed had 25 times more foreign seeds than graded seed.

6.10.2 Manage weeds in non-crop areas

Weed infestations often commence in non-crop areas (e.g. around buildings, along roadsides, along fencelines, around trees) (Photo 8). Controlling these initial populations will prevent weeds from spreading to other parts of the property. These areas have become primary sources of glyphosate-resistant weeds, which then spread into paddocks. This is particularly important for weeds with wind-blown seed.

Weeds along fencelines, paddock edges and non-crop areas of crop paddocks can be controlled by a combination of knockdown herbicides, hay or silage cutting and/or cultivation. Unlike other activities, timing for fenceline weed control is reasonably flexible with a wide window of opportunity, although control should be carried out before seed is viable.

41 GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-2-herbicides-and-killing-weed-seedlings

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

Photo 8: *Flaxleaf fleabane along this fence will easily spread into neighbouring fields.*

Source: A. Storrie

6.10.3 Clean farm machinery and vehicles

Machinery and vehicles are major sources for the introduction of new weeds. Earthmoving equipment, harvesters, balers and slashers are particular problems.

Ensure machinery and vehicles have been cleaned prior to entry to a farm or cleaned at a specially designed wash station. Within a farm, harvest from the cleanest to dirtiest paddock to minimise the spread of weed seeds. Where breakdowns require in-field repair, mark the position with a GPS and diarise to check for weed germinations.

6.10.4 Livestock feeding and movement

Weeds can be introduced in stock feed and in livestock over long distances, particularly during droughts. Ensure that fodder source is known. New stock or stock returning from agistment need to be kept in a holding paddock for seven days to enable the bulk of seed in their intestines to be excreted. [43]

MORE INFORMATION

IWM section 5: Tactics

Farm biosecurity: Grains

GRDC video links:

GRDC webinar on managing weeds on fencelines

VIDEOS

SANTFA: Summer weed control

WeedSmart: Understanding pre-emergent herbicides

WeedSmart: When is it worth rotating from Select to Factor?

43 GRDC (2014) Section 8. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, https://grdc.com.au/resources-and-publications/iwmhub/section-8-managing-farm-hygiene

GRDC VIDEOS

Advances in weed management: Spray application in summer fallows

Advances in weed management: Stubble and soil binding of pre-emergent herbicides for annual ryegrass control in winter crops

Crop competition for weed management—narrow row spacings

Double knock applications—a grower's experience

Double knock applications—double knock strategies for resistant weed populations

Double knock applications—target weed species and application strategy

Spray application of herbicides—application volume in stubble

Spray application of herbicides—applying Group A (ACCAse inhibitor) herbicides

Spray application of herbicides—nozzle selection

Spray application of herbicides—spray deposition

Spray application of herbicides—travel speed

Weed seed bank destruction—Weed Seeker

GCTV10: Double knock timing

GCTV11: Strategic tillage, does no-till mean never till?

Photo 9: *This creek line is infested with glyphosate-resistant annual ryegrass and a range of other weeds. During the next flood, these seeds will spread across previously clean paddocks.*

Source: A. Storrie