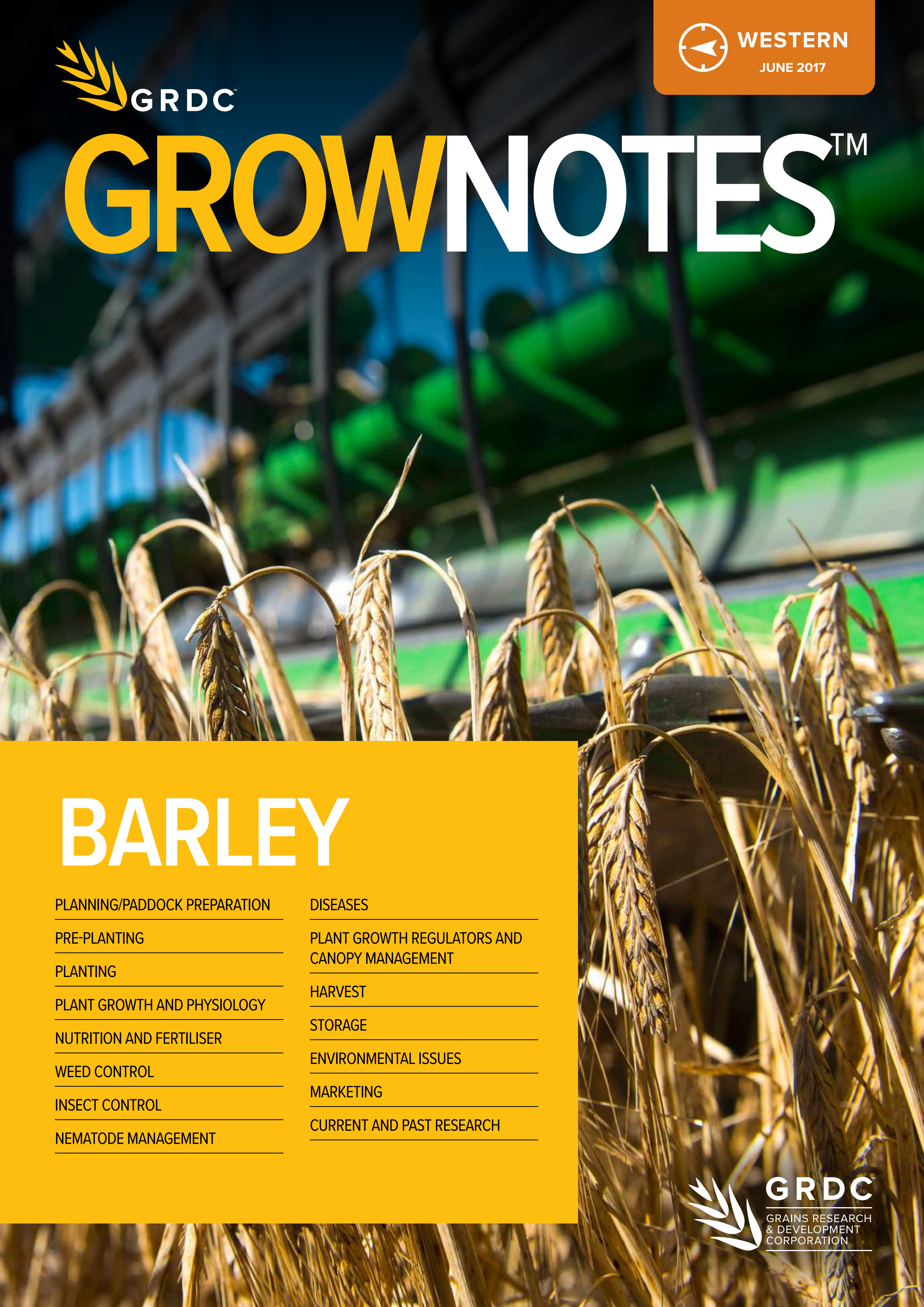

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GROWNOTES™

BARLEY

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

ISBN: 978-1-921779-33-6

Start here for answers to your immediate barley crop management issues

Should I target feed or malt barley?

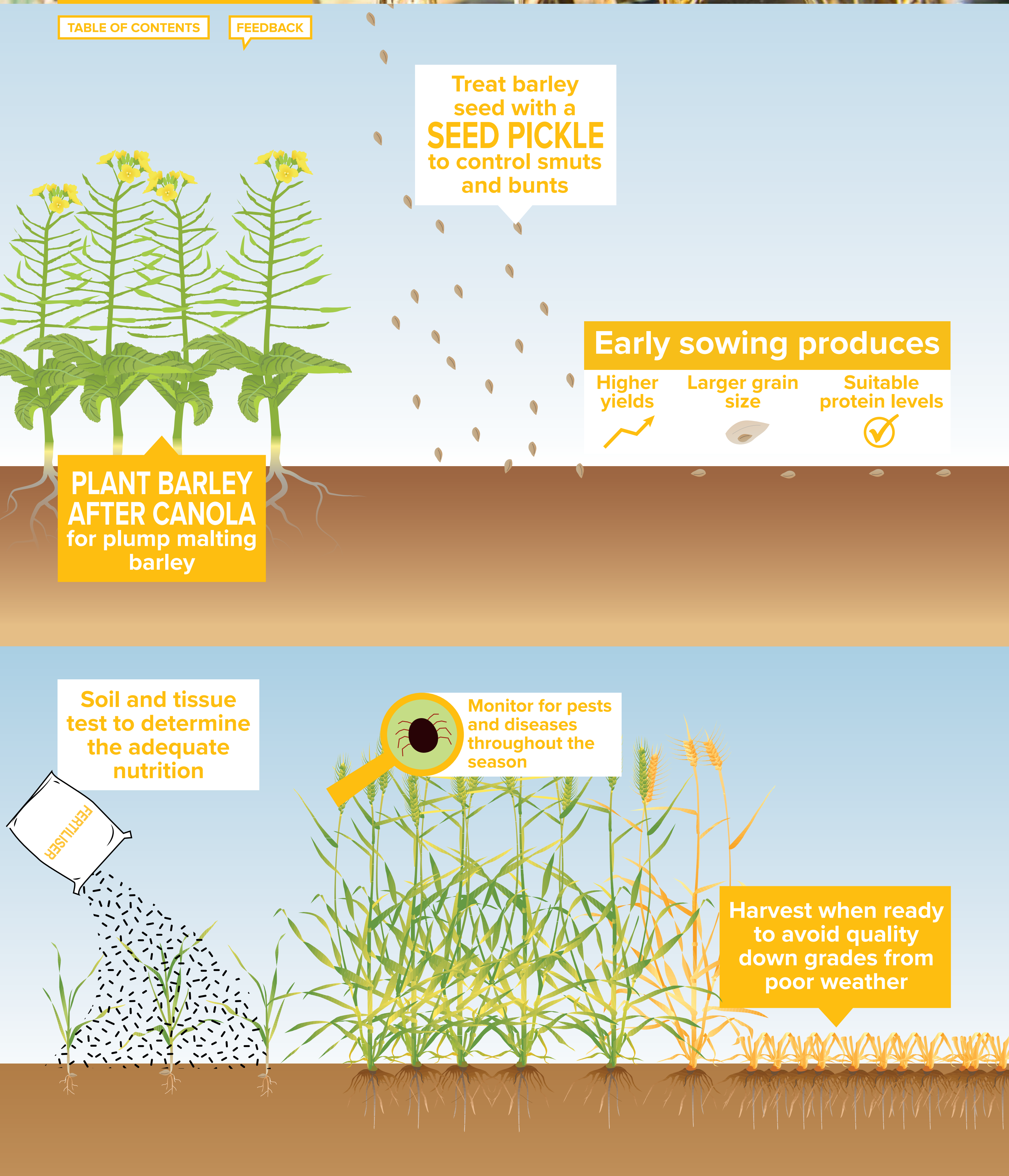
What variety should I grow?

What are the advantages of early sowing?

How do I manage foliar diseases such as rust?

How can I improve crop competition with weeds?

If harvest is delayed what are the costs?


Treat barley seed with a SEED PICKLE to control smuts and bunts
Early sowing produces
Higher yields
Larger grain size
Suitable protein levels
PLANT BARLEY AFTER CANOLA for plump malting barley
Soil and tissue test to determine the adequate nutrition
FERTILISER
Monitor for pests and diseases throughout the season
Harvest when ready to avoid quality down grades from poor weather

Contents

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1 Planning/Paddock preparation

Introduction

A.1 Crop overview

Barley (*Hordeum vulgare*) is a widely grown and highly adaptable winter cereal crop used mainly for the production of malt for the brewing industry and for stock feed.

Barley is an annual plant that has been selected from wild grasses. It is thought to have been an important food crop from as early as 8000 BCE (Before Common Era) in the Mediterranean and Middle East region (Photo 1).

Because of barley's tolerance of salinity, by 1800 BCE it had become the dominant crop in irrigated regions of southern Mesopotamia, and it was not until the early CE period that wheat became more widely grown.

Photo 1: *Barley has long been an important food crop.*

Source: Rachel Bowman (Seedbed Media)

Planting

Barley is very versatile in its planting time, being slightly more frost tolerant (1°C) than wheat prior to ear emergence and at flowering, and can be planted earlier in the season. [1]

For more information, see Section 14.1: Frost.

It is also often a better option than wheat for late planting, especially if feed-grain prices are good. Preferred planting times are from late April to mid-May but this will vary for each region, depending on frosts and seasonal effects.

Early planting may produce higher yields, larger grain size and lower protein levels, making it more likely to achieve malt quality. However, early crops are more likely to have exposure to frost and growers should assess the frost risk for their area prior to sowing. Late plantings will often mature in hot dry weather, which can reduce grain size, yield and malting quality.

Nitrogen

Management of nitrogen (N) availability is vital to achieve optimal yields and quality in barley crops. The level of N and plant available water will impact strongly on yield and protein, which impacts on crop return. Unlike wheat where premiums are available

1 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

for high protein, premiums for malting require moderate proteins of 9.5–12.5% for Malt1. [2]

Production

Australia produces high-quality two-row spring-type barley, with annual production averaging ~7.5 Mt/year. It is a widely grown crop (second only to wheat) and occupies a large geographic area—almost 4 M/ha, dispersed from Western Australia (WA) to southern Queensland.

According to Grain Industry of Western Australia (GIWA), WA produced more than four million tonnes of barley in 2016 and yielded an estimated 2.96 tonnes per hectare.

Australia has an enviable reputation for producing a reliable supply of high-quality, contaminant-free barley that is sought after by the malting, brewing, distilling, shōchū (Japanese distilled spirit) and feed industries.

Australia produces around 2.5 Mt of malting barley and 4.5 Mt of feed barley; the average Australian malting selection rate is the highest of the world's exporting nations, with ~30–40% of the national crop selected as malting.

Domestically, malting barley demand is ~1 Mt/year and Australian domestic feed use ~2 Mt/year. Domestic brewers are tightly linked to Australia's barley production, and strong relationships exist between all facets of the industry, from breeder to brewer and all stages in between.

A.1.1 Western Australian barley industry

Barley is WA's second most important crop after wheat delivering the State around $1 billion in export grain and malt earnings in recent years. Production area remains relatively constant while production has more than doubled from 2000 to 2016 (Figure 1). Western Australia is a leading supplier of malting barley to China and shōchū barley to Japan and a major supplier of feed barley to the Middle East and China (Photo 2). The Department of Agriculture and Food WA (DAFWA) is involved in all aspects of the barley value chain from variety development and assessment through to grain quality research and market intelligence to determine export market needs.

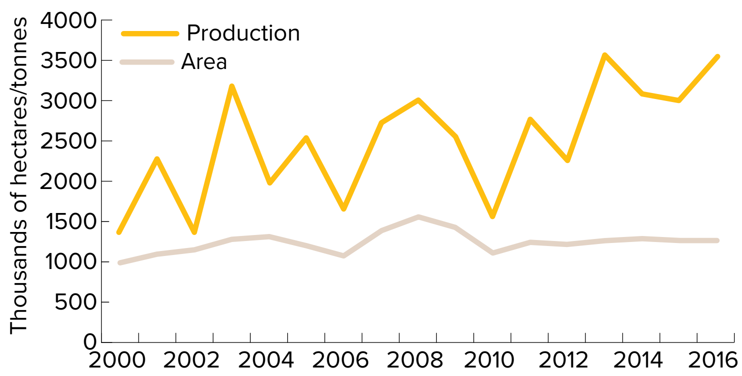

Figure 1: *WA Barley Area and Production 2000 to 2016.*

Source : DAFWA

There are two malting plants in WA, Joe White in Forrestfield and Kirin in Welshpool. The Joe White facility is the largest barley malting facility in the Southern Hemisphere. Between the two plants, about 250,000 tonnes of barley are malted each year, with the majority of the malt being exported.

2 CBH Dellivery Standards

A national pilot malting facility established in WA in 2010 has enabled smaller quantities of malting barley to be tested using commercial malting processes. The pilot plant will speed the identification of promising new malting barley varieties and also enable the beer-quality attributes of WA malting varieties to be demonstrated to export customers.

Exports

The majority of barley produced in WA is exported, delivering the state about $800–900 million in export revenue. Malt exports are worth an additional $120 million each year for the state.

As the nation's largest producer of malting barley, WA provides the majority of these exports to China with 40% of barley produced delivered as malting grade. The remaining 60% is delivered as feed grade, the majority of which is sent to the Middle East, although China is emerging as a major market for feed barley as well. [3]

Brand identity for WA

With beer consumption on the rise in South-East Asia, the South East Premium Wheat Growers' Association (SEPWA) is looking to generate a brand identity for WA malting barley.

In 2016 the Esperance-based grower group received $413,410 through the DAFWA Grower Group Research and Development Program to fund a three-year project.

The 'barley brand development for Asian consumers' project will develop a working relationship between the Asian-based malting company Intermalt and growers in the Esperance Port Zone.

The relationship with Intermalt, an arm of Interflour which is partly owned by Co-operative Bulk Handling Ltd, will integrate market end-user intelligence and on-farm agronomy to try to establish WA barley as a preferred supply source for Asian brewers.

SEPWA's field-trials program will conduct further technical assessment of WA barley. Testing varieties for malting suitability will help to introduce new varieties to the marketplace, as well as optimise already proven barley varieties.

SEPWA will supply barley samples from variety trials for three seasons for pilot and micro malting testing with Intermalt and the Australian Export Grains Innovation Centre.

It is expected the result will be the faster adoption of new barley genetics for WA growers, as well as the establishment of WA barley as a premium supply source. This will help growers understand the agronomic effects on end-user performance and market demand, and also help develop supply-chain relationships. Grower and end-user relationship is critical to the overall brand development of WA barley, as well as further developing grain export opportunities in Asia. [4]

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3 I Wilkinson (2016) Western Australian barley industry. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1464

4 GRDC (2016) WA malt barley push into Asia. GRDC Ground Cover Issue 124, September-October 2016, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-124-SeptemberOctober-2016/WA-malt-barley-push-into-Asia

Photo 2: *WA is a leading supplier of malting barley to China.*

Over the past five years, Australian barley farmers produced an average of 7.5 Mt of grain per year, of which around two-thirds was exported.

Australia is the world's second-largest exporter of barley and supplies almost 30% of the world's barley trade. Saudi Arabia, Japan and China are large importers of Australian barley, and these markets are growing rapidly. [5]

In addition, Australia exports around 1.5 Mt of malting barley and ~2.5 Mt of feed barley representing ~20% of the global feed-barley trade. Major exporting states are WA and South Australia, where domestic demand for malting and feed barley is considerably smaller than in the eastern states. [6]

Varieties

Selecting a variety with proven performance in the region is important. If trying a new variety, it is important to compare it with a variety previously grown. Factors to take into consideration for variety selection include:

- suitability of the variety for the region
- time of planting
- available moisture at planting
- disease risks
- yield potential
- standability and straw strength
- soil N status (i.e., starting N levels not high for malting barley)
- marketing options—malt versus feed
- rotation (past crops and future planting intentions)
- availability of seed [7]

Barley growers have access to a number of barley varieties. Identifying the variety that is best suited to a region and that will give the greatest return requires consideration of factors including relative yield, disease resistance, the probability of achieving particular quality grades and their associated prices.

The decision to grow either a malting or feed variety may depend on one or more factors, including: the difference in income between malting and feed grades relative to yield differences i.e. the gross margin; the probability of producing a malting grade barley; availability of malting storage segregations in storage facilities; and disease resistance and agronomic considerations.

Contact grain marketers to discuss market demand prior to sowing a malting variety. Malting barley is grown, stored and sold on a variety-specific basis and it is

5 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

6 Barley Australia (2014) Industry information. Barley Australia, http://www.barleyaustralia.com.au/

7 DAF Qld (2013) Barley planting and disease guide. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-disease-guide

important to ascertain whether the variety chosen can be stored and marketed in a particular area. [8]

Malting quality

Paddock selection and N management are often the keys to producing malting quality. [9] Growers should record paddock rotations and use soil and tissue testing to ensure adequate nutrition.

Use adequate N fertiliser but do not overfertilise because this will encourage excessive vegetative growth and could result in lodging. If applied late, it could also result in excess protein levels (above malting requirements). Phosphorus, zinc and sulfur levels are also important. A starter fertiliser is recommended. [10]

MORE INFORMATION

GRDC (2014): Barley holy grail. Driving agronomy podcast

GIWA (2016) Grain standards in Western Australia.

End–uses

Australian barley is highly regarded around the world. Uses for Australian malted barley include:

- beer
- shochu, whiskey and other distilled spirits
- malt extract
- malt vineger
- confectionary
- flavoured sweet drinks
- breakfast cereals [11]

A.2 Malt and feed barley

Malt is produced from a cereal grain (usually barley) that has been allowed to germinate for a limited period of time prior to undergoing a mild kilning.

During the malting process, raw barley is steeped, germinated and kilned to change the raw barley seed into a friable, biscuit-like texture, which from the outside looks just like a barley kernel.

It is then easily crushed in the brewery mill in preparation for the sugar conversion that takes place in the brewery mash tun. The malting process converts ~10% of the carbohydrate in the raw grain into fermentable sugars via the process of germination. The malting process prepares the grain for more modification, which will be undertaken in the brewhouse.

For the Australian barley industry, there are two distinct markets to service—a domestic market and an export market—each of which has different requirements and needs for malt and raw barley. This is due to fundamentally different styles and methods of brewing. In Australia brewers use sugar as an adjunct, whereas in Asia solid adjuncts such as rice are predominantly used in the brewing process.

The malting process causes numerous chemical reactions to occur between amino acids and reducing sugars to develop colour and flavour compounds. Malt extract is a natural flavouring and colouring that is high in protein and natural sugars, and is a major natural energy source. In addition to its use in brewing, it is widely used in baking, confectionery, breakfast cereals, malt beverages, dairy products and condiments, and as a caramel substitute.

8 Agriculture Victoria (2016) Growing barley. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-barley

9 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2014. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

10 DAF Qld (2013) Barley planting and disease guide. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-disease-guide

11 AEGIC (2016) Barley. Australian Export Grains Innovation Centre, http://aegic.org.au/about/australian-grains/barley/

Australia produces >900,000 t of malt per year, with ~200,000 t consumed domestically (predominantly in the brewing industry) and >700,000 t exported predominantly into the Asian regional marketplace. [12]

Maltsters and brewers require brightly coloured barley for the production of high quality malt and brewed products. Poorly coloured or stained barley will only be bought as a last resort as it presents specific problems to end users. For example, weather stained barley will sometimes carry its poor colour through to the end product. Barley with fungal staining can cause more severe problems such as a low level of malt extract in the malt house, poor flavour, gushing or overfoaming and reduced shelf life of any beer produced from it.

Low moisture content is also important in malting barley, particularly when it is being stored for any length of time. Moisture levels above 12.5% in stored barley will promote fungal growth and cause the problems outlined above.

Protein is also an important factor when marketing malting barley. The ideal protein range is between 9.5–12.5%. Barley with protein levels either side of this range will cause quality problems in the end product and produce less malt extract per tonne.

Other quality aspects considered by malt barley buyers include grain plumpness and weight. The heavier the grain, the more malt per tonne will be extracted. Malting barley must also be of the one variety as each variety of barley behaves differently in the malthouse. Screenings and skinned grains must also be kept to a minimum as these will cause uneven germination during steeping and inconsistent malt. [13]

A.2.1 Feed barley

Barley is used as stock feed, especially in the intensive pig, poultry, dairy and beef industries. This demand is met by varieties specifically grown as high-yielding feed types as well as grain that does not meet the quality requirements for malting or human food.

A few varieties are suitable as a dual-purpose crop (i.e. for grazing by livestock and for grain). Other varieties lose too much yield potential if grazed. When barley crops are grazed, care must be taken with the use of pesticides. Observe the withholding periods for grazing or cutting for hay or silage. [14]

The two most important factors considered by feed barley buyers are grain colour and moisture content.

Grain brightness is important as many purchasers of feed barley on-sell to other end users. Primary buyers of feed barley will therefore attempt to purchase the brightest grain possible to increase their chances of on-selling at a premium price. In WA this means feed producers will prefer BFED1 over BFED2

Moisture levels are important for storage reasons. Feed barley is often stored for long periods and excessively moist barley will decline in quality due to the growth of microflora during storage.

Protein is a minor consideration for buyers of feed barley as it is bought primarily for its energy content rather than as a protein source. [15]

MORE INFORMATION

2017 Barley variety sowing guide for Western Australia

12 Barley Australia (2014) Industry information: Malt. Barley Australia, http://www.barleyaustralia.com.au/barley-and-malt

13 DAFWA (1995) The Barley Book. Department of Agriculture and Food, Western Australia, http://researchlibrary.agric.wa.gov.au/bulletins/44

14 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf.

15 DAFWA (1995) The Barley Book. Department of Agriculture and Food, Western Australia, http://researchlibrary.agric.wa.gov.au/bulletins/44/

Planning/Paddock preparation

Growers planning to plant barley should use market signals to assist them when deciding which varieties to sow. Market demand, pricing signals and the location of segregations should be considered in partnership with the agronomic management needed. Consideration should also be given to the risk associated with delivering malt/food grade barley when determining how much area to plant to each malt/food variety. [1]

1.1 Paddock selection

Paddock selection is critical for reliable malting barley production, but less important for feed barley. When selecting paddocks to grow barley, consider the following:

- Nitrogen status should be appropriate for expected yield level
- Soil pH($CaCl_2$) should be ≥5.0 and soil aluminium <5%
- Avoid soils prone to waterlogging
- In rotation, ideally sow after a root-disease break crop
- Avoid barley on barley
- Barley may be sown after wheat if disease or seed contamination is not a problem
- Avoid varietal contamination.

Results from research in the southern grains region suggest that paddocks with pre-sowing soil nitrate-N levels >150 kg/ha are unsuitable for malting barley production. Paddocks with pre-sowing nitrate-N of 100–150 kg/ha were less likely to achieve barley of malting quality than those with <100 kg/ha. [2]

Informed paddock selection, suitable crop rotation and the planting of disease-resistant varieties are the best tools to minimise disease.

Paddock rotation and history

Crop sequencing/rotation is a key part of a long-term approach to tackling weed, disease and moisture challenges in farming systems.

1.1.1 Benefits of barley as a rotation crop

Barley is a good rotation crop for breaking disease and weed cycles, and providing high stubble levels. [3] It fits well into the farming systems as a winter cereal crop.

Advantages of barley include:

- less susceptible to frost than wheat at early growth stages
- somewhat lower N fertiliser requirements than wheat if expecting similar yields
- matures faster and can be harvested earlier than wheat
- vigorous plant growth and high Water Use Efficiency (WUE)
- vigorous early growth—some varieties establish groundcover, which smothers weeds
- produces more dry matter than wheat, leaving very good stubble cover and valuable straw for livestock feeding

1 DAFWA (2016) 2017 barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

2 L Lenaghan, T Fay, M. Evans (2001) Paddock selection is critical for reliable malt barley production. Australian Agronomy Conference/the Regional Institute, http://www.regional.org.au/au/asa/2001/4/b/lenaghan.htm

3 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

- as a cereal can iregrow to produce a good grain crop when grazed before stem elongation
- a good break crop due to differences in foliar disease responses compared with wheat.

Growers should soil and plant tissue test and record paddock rotations to determine adequate crop nutrition. [4]

1.1.2 Disadvantages of cereals as a rotation crop

Growing cereals in continuous production can be difficult because of the rising incidence of:

- difficult-to-control and herbicide-resistant weeds, particularly grass weeds
- disease build-up (e.g. crown rot, *Rhizoctonia*, cereal cyst nematode, root lesion nematode, take-all)
- N depletion and declining soil fertility.

Crop rotation is a key strategy for managing Australian farming systems, and improvements in legume and oilseed varieties and their management have facilitated this shift.

In many of Australia's grain-growing regions, broadleaf crop options have been seen as riskier and less profitable than cereals. This perception has been driven, in part, by fluctuating prices and input costs associated with the broadleaf crop in the year of production, and difficulties in marketing. However, when the profitability of the entire rotation is assessed, it is often more profitable to include broadleaf crops in the crop sequence.

A broadleaf crop is often included in the crop sequence to counteract limitations in the cereal phase (weeds, disease, N), so the broadleaf crop's financial impact may be considerably better if considered across the crop sequence. [5]

Examples of rotations and their suitability for the production of malting barley

- **Following canola**: With the advantage of low root disease incidence and reduced soil N supply after oilseeds, this is the ideal situation for the production of plump malting barley that is not too high in protein.
- **Following oats**: This rotation is again well suited to the production of malting barley as take-all will be reduced and soil N level lowered. Oats are quite tolerant of waterlogging whereas barley is very susceptible, so be careful not to choose a high-risk waterlogging paddock on which oats happened to have yielded well.
- **Following pasture**: The suitability of barley as a crop after pasture will depend on the soil N status and soil type. After a good medic stand on heavy soils it is likely that soil N would be too high and wheat would be a much more profitable alternative. On lighter soils with a weaker clover base, barley would be a better proposition.
- **Following field peas**: On heavy soils, barley following field peas is likely to lead to high protein levels in most years, rendering it unsuitable for malting. Feed barley can be grown in this situation but the returns are unlikely to be competitive with high protein wheat.
- **Second cereal following field peas**: Barley is well suited to the role of second cereal in the rotation unless soil N levels are very high.
- **Following lupins**: On light soils, barley following lupins is likely to yield well but the protein level may be a problem depending on soil N supply. If wheat following lupins generally gives protein levels of 10.5% or more then it is likely

4 DAF Qld (2014) Barley—planting and disease guide. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/__data/assets/pdf_file/0003/145587/Barley-Planting-Guide-2014.pdf

5 M Peoples (2012) Returns from break crops can challenge wheat. GRDC Ground Cover Issue 98, 27 April 2012, http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-98-Supplement-Crop-Sequencing/Returns-from-break-crops-can-challenge-wheat

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GRDC (2013) Crop sequencing—what are the key issues to making profitable and sustainable decisions? GRDC Update Papers.

GRDC Online Farm Trials: Barley and wheat disease management using foliar and fertiliser fungicides.

that soil N will be too high for malting barley. Likewise, wheat protein levels of 10.5% or less indicate that malting barley can be safely grown in most years.

- **Second cereal following lupins**: Where take-all levels may be high following the wheat crop, barley yield is likely to be restricted to around 2 t/ha when grown as the second cereal. [6]

1.2 Fallow weed control

Summer weeds can rob subsequent crops of soil N and stored soil water. They can also reduce crop emergence by causing physical and/or chemical interference at seeding time.

Controlling summer weeds early will conserve valuable soil N and moisture for use by the crop during the following season. A WA grower at Salmon Gums has reported an average farm crop yield increase of 400 kg/ha since the adoption of consistent summer weed control.

A study by the Cooperative Research Centre (CRC) for Australian Weed Management found summer weeds can lock away large amounts of N in the weedy biomass, rendering it unavailable for crop growth. Weed burdens of 2.5 t/ha can cause a net loss of available soil N and burdens of more than 3 t/ha can reduce subsequent wheat yields by as much as 40%. [7]

Paddocks generally have multiple weed species present at one time, making weed-control decisions more difficult. Knowing the paddock and controlling weeds as early as possible are important for good control of fallow weeds. Information is included for the control of most common problem weeds. For advice on individual paddocks, growers should contact their agronomists. See Section 6: Weed Control.

Return on investment

Benefits of fallow weed control are significant. In low-rainfall areas across Australia, growers are likely to gain financially from summer weed control, according to the Agricultural Production Systems Simulator (APSIM) simulations. For low-rainfall areas, there is a 70–99% chance of making a profit from summer weed control. The greatest impact was calculated in areas with a higher proportion of summer rain.

The highest return on investment in summer weed control is likely to be on loams, light clays and loamy duplex soils or soils with a plant available water capacity of more than 100 mm. Returns will be better in the part of the rotation where soil water that would support continued weed growth is already present, for example, pulse stubbles or long fallows. In high-rainfall areas, the potential for an economic return is lower and more variable than low-rainfall areas. The chance of making a profit from summer weed control is 30–80%. Despite this, it is important not to avoid summer weed control. Uncontrolled weed growth in high-rainfall areas is likely to lead to a rapid build-up of weeds and disease, reducing returns in the short to medium term. [8]

Effective weed control can reduce weed numbers in subsequent years and run down the seedbank. Uncontrolled weeds contribute massively to the soil seed bank, creating increased costs of control and future weed burdens. This may limit crop choice and reduce flexibility in systems.

Summer weed control can be expensive but is necessary to prevent problems with excessive growth and/or moisture and N loss from the soil. [9]

6 DAFWA (1995) The Barley Book. Department of Agriculture and Food, Western Australia, http://researchlibrary.agric.wa.gov.au/bulletins/44/

7 DAFWA (2016) Summer weeds. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2516

8 GRDC (2012) Summer fallow—make summer weed control a priority. Western Region. Summer Fallow Management Fact Sheet, January 2012

9 DAFWA (2016) Summer weeds. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2516

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GRDC (2011) Achieving good pre-emergent spray results. GRDC Update Papers.

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1.3 Fallow chemical plant-back periods

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. This is the case with sulfonylureas (SUs, e.g. chlorsulfuron).

Residual persistence and half-lives of common herbicides are shown in the Table 1. Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the SUs. 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. [10]

There are also in-crop herbicides that have plant-back periods. Some are mentioned in Table 1.

Table 1: *Half-life of common pre-emergent herbicides and residual persistence from broadacre trials and paddock experiences*

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–1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Long-lasting activity observed 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. Long-lasting (>3 months) activity observed on broadleaf weeds such as fleabane
Simazine	60 (range: 28–149)	Med./high. 1 year of residual in high-pH soils. Long-lasting (>3 months) activity observed on broadleaf weeds such as fleabane
Terbyne® (terbuthylazine)	3-60 in biologically active soil	High. Long-lasting (>6 months) activity observed on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Long-lasting activity observed on grass weeds such as black/stink grass
Stomp® (pendimethalin)	40	Medium. 3–4 months of residual
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months of residual
Balance® (isoxaflutole)	1.3 (metabolite: 11.5)	High. Reactivates after each rainfall event. Long-lasting (>6 months) activity observed on broadleaf weeds such as fleabane and sow thistle

10 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

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GRDC Online Farm Trials: Residual herbicides. Group B & C carry-over.

BASF: Clearfield Production System

WA Barley Variety Guide 2017

https://www.agric.wa.gov.au/barley/2017-barley-variety-sowing-guide-western-australia

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®
Ally® (metsulfuron-methyl)	30 (range: 14–180)	Persists longer in high-pH soils and after a dry year

Sources: CDS Tomlinson (ed.) (2009) The pesticide manual. 15th edn. British Crop Protection Council, Farnham, UK. Extoxnet. California Dept Pesticide Regulation Environmental Fate Reviews.

1.3.1 Avoid damage from residual herbicides

Select an appropriate herbicide for the weed population present and consider what the re-cropping limitations may do to future rotation options. Read the entire herbicide label, including the details in fine print.

Users of chemicals are required to keep good records, including weather conditions. In the case of unexpected damage, accurate records can be invaluable, particularly spray dates, rates, batch numbers, rainfall, soil type(s) and pH.

If chemical residues could be present, choose the least susceptible crop (refer to product labels). Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues.

Be wary of compounding a residue problem by planting a herbicide-resistant crop and spraying with more of the same herbicide group. Growers may avoid the problem with residues in the short term, only to be faced with herbicide-resistant weeds in the longer term. This can also have an additive effect on non-herbicide-resistant crops. [11]

1.3.2 Genetic controls

The Clearfield® Production System is designed to deliver extended weed control and increased yield potential and crop quality. [12] It matches selected seed varieties with Intervix® (active ingredients imazamox and imazapyr), a custom-designed herbicide that can only be used on Clearfield® varieties. Refer to the herbicide label for weed species that can be controlled.

In 2013 Australian growers were offered access to the world's first registered Clearfield® barley, Scope. In 2017, a new Clearfield® variety with improved traits, Spartacus CL$^{\Phi}$, was released.

1.4 Seedbed requirements

Barley seed needs good soil contact for germination. Some 70–90% of seeds sown produce a plant. Inappropriate sowing depth, disease, crusting, moisture deficiency and other stresses all reduce the numbers of plants that become established. Field establishment rates can be ≤60% if seedbed conditions are unfavourable. [13]

11 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

12 Crop Care (2011) Clearfield best management practice. Crop Care Australasia Pty Ltd, http://www.cropcare.com.au/Assets/501/1/2011ClearfieldBMPWeb.pdf

13 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

1.5 Soil moisture

APSIM-Barley

The APSIM-Barley module of APSIM simulates the growth and development of a barley crop in a daily time-step on an area basis (per m^2, not single plant). [14]

This can be a useful tool for barley growers. For more information, visit: APSIM-Barley.

1.5.1 Subsoil constraints

Soils with acidic subsoils, compactions layers or high levels of chloride and/or sodium or boron in their subsurface layers are often referred to as having subsoil constraints. There is growing evidence that subsoil constraints affect yields by increasing the lower limit of a crop's available soil water and thus reducing the soil's PAWC. [15]

1.6 Yield and targets

1.6.1 Variety yield comparisons

See the National Variety Trial website to compare the performance of current barley varieties in WA. See Section 2.2: Varieties for information on barley varieties.

1.6.2 Seasonal outlook

The Department of Agriculture and Food, Western Australia (DAFWA) provides up to date information about the coming season and its potential impacts on cropping and agriculture. To assist in making more informed on-farm decisions, DAFWA provides statistical seasonal rainfall forecasts, modelled plant available soil water at the start of the growing season and risk of frost occurring at different locations. The Statistical Seasonal Forecast (SSF) system uses historical relationships between global sea surface temperature and sea level pressure with rainfall in south-west Australia to produce forecasts of rainfall for future months. DAFWA seasonal climate information can be found at https://www.agric.wa.gov.au/drought/seasonal-climate-information.

For tips on understanding weather and climate drivers including the Southern Oscillation Index, visit the Climate Kelpie website. Case studies of farmers across Australia recruited as 'Climate Champions' as part of the Managing Climate Variability R&D Program can be accessed at: Climate Kelpie MCV Climate Champion program.

Australian CliMate is a suite of climate analysis tools delivered on the Web, iPhone, iPad and iPod Touch devices. CliMate allows users to interrogate climate records to ask questions relating to rainfall, temperature, radiation, and derived variables such as heat sums, soil water and soil nitrate, as well as El Niño/Southern Oscillation status. It is designed for decision-makers such as farmers whose businesses rely on the weather. Download from the Apple iTunes store at: https://itunes.apple.com/au/app/australian-climate/id582572607?mt=8.

One of the CliMate tools, Season's Progress?, uses long-term (1949 to present) weather records to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and all years. It explores the readily available weather data and compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons.

Crop progress and expectations are influenced by rainfall, temperature and radiation since planting. *Season's Progress?* provides an objective assessment based on long-term records and helps to answer the following questions:

14 APSIM. Crop module documentation: Barley. Agricultural Production Systems Simulator, http://www.apsim.info/Documentation/Model,CropandSoil/CropModuleDocumentation/Barley.aspx

15 Z Hochman et al. (2007) Simulating the effects of saline and sodic subsoils on wheat crops growing on Vertosols. Australian Journal of Agricultural Research 58, 802–810, http://www.publish.csiro.au/paper/AR06365.htm

- How is the crop developing compared with previous seasons, based on heat sum?
- Is there any reason why my crop is not doing as well as usual—because of below-average rainfall or radiation?
- Based on the season's progress (and starting conditions from *HowWet/N?*), should I adjust inputs? [16]

1.6.3 Fallow moisture

For a growing crop, there are two sources of water: that stored in the soil before planting, and that falling as rain while the crop is growing. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry. [17]

HowWet?—a climate analysis tool

HowWet? estimates how much rain has been stored as plant-available soil water during the most recent fallow period; it estimates how much N has been mineralised as nitrate-N in soil; and it provides a comparison with previous seasons. This information aids in the decision of what crop to plant and how much N fertiliser to apply.

1.6.4 Water Use Efficiency

Water Use Efficiency is the measure of a cropping system's capacity to convert water into plant biomass or grain. It includes the use of both water stored in the soil and rainfall during the growing season.

Water Use Efficiency relies on:

- soil ability to capture and store water
- crop ability to access water stored in the soil and rainfall during the season
- crop ability to convert water into biomass
- crop ability to convert biomass into grain (harvest index).

The French–Schultz approach

In southern Australia, the French–Schultz model is widely used to provide growers with a benchmark of potential crop yield based on available soil moisture and likely in-crop rainfall.

In this model, potential crop yield is estimated as:

Potential yield (kg/ha) = WUE (kg/ha.mm) × (crop water supply (mm)–estimate of soil evaporation (mm))

where crop water supply is an estimate of water available to the crop, i.e. soil water at planting plus in-crop rainfall minus soil water remaining at harvest.

The French–Schultz model has been useful in providing growers with performance benchmarks; where yields fall well below these benchmarks, it may indicate something wrong with the crop's agronomy or a major limitation in the environment. There could be hidden problems in the soil such as root diseases, or soil constraints affecting yields. Alternatively, apparent underperformance could be simply due to seasonal rainfall distribution patterns, which are beyond the grower's control. [18]

MORE INFORMATION

GRDC (2012) Water Use Efficiency of grain crops in Australia: principles, benchmarks and management.

16 J Sabburg, G Allen (2013) Seasonal climate outlook improvements changes from historical to real time data. GRDC Update Papers, 18 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Seasonal-climate-outlook-improvements-changes-from-historical-to-real-time-data

17 J Whish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Papers, 23 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW

18 GRDC (2009) Converting rainfall to grain. Northern Region. Water Use Efficiency Fact sheet, https://grdc.com.au/__data/assets/pdf_file/0029/225686/water-use-efficiency-north.pdf.pdf

1.7 Disease status of paddock

PestFax is a free weekly informative and interactive reporting service during the growing season. It provides risk alerts, current information and advice on pests and diseases threatening crops and pastures throughout the grain belt of WA during each growing season. Diseases remain a major threat to barley production in Australia but are generally well controlled. In 2009, the average annual loss from barley diseases is estimated at AU$252 million, or $66.49/ha. “

Continuous cereal cropping increases the risk of diseases such as crown rot.

See Section 9: Diseases for more information on diseases.

1.7.1 Soil testing for disease

PreDicta B is a DNA-based soil testing service to identify which soilborne pathogens pose a significant risk to broadacre crops prior to seeding.

It has been developed for cropping regions in southern Australia and includes tests for:

- CCN (*Heterodera avenae*)
- take-all (caused *by Gaeumannomyces graminis* var. *tritici (Ggt*) and *G. graminis* var. *avenae (Gga))*
- Rhizoctonia bare patch (caused by *Rhizoctonia solani* AG8)
- RLN (*Pratylenchus neglectus, P. thornei* and *P. Quasitereoides*
- crown rot (caused by *Fusarium pseudograminearum*)
- stem nematode (*Ditylenchus dipsaci*).

Continuous cereal cropping increases the risk of diseases but testing gives growers the ability to identify soil diseases prior to planting.

Grain producers can access PreDicta B from Primary Industries and Regions SA/South Australian Research and Development Institute. Samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program.

PreDicta B is not intended for in-crop diagnosis. This is best achieved by sending samples of affected plants to the local plant pathology laboratory. DDLS–Plant pathology services WA.

For more information, visit: PreDicta B.

1.8 Nematode status of paddock—testing of soil

Root-lesion nematodes (RLN) are found over 5.74 million hectares (or ~65%) of the cropping area of Western Australia. Populations potentially limit yield in at least 40% of these infested paddocks.

The main species found in broadacre cropping in WA are *Pratylenchus neglectus*, *P. quasitereoides* (originally described as *P. teres*), *P. thornei* and *P. penetrans*.

Barley may be more susceptible to *P. quasitereoides* than to *P. neglectus*. [19]

Paddocks should be tested for plant parasitic nematodes so that optimal management strategies can be implemented. Testing will tell growers and advisers whether nematodes are present and at what density, and which species are present.

It is important to know which species are present because crops and varieties have different levels of tolerance and resistance to different species of nematodes.

Diagnosis of RLN is difficult and can be confirmed only with laboratory testing, particularly to identify the species because all RLN species cause identical symptoms.

19 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region. Fact sheet, http://www.grdc.com.au/Resources/Factsheets/2015/03/Root-Lesion-Nematodes

If RLN infestation is suspected, growers are advised to check the crop roots. Carefully digging up and washing the soil from the roots of an infected plant can reveal evidence of infestation in the roots, which warrants laboratory analysis.

Testing services are available at Agwest Plant Laboratory at the Department of Agriculture and Food, Western Australia (DAFWA), and the DNA-based soil testing service PreDicta B, provided by the South Australian Research and Development Institute, can detect *P. neglectus*, *P. thornei* and *P. quasitereoides*. Growers are advised to contact their local DAFWA office for advice. [20]

If a particular species is present in high numbers, immediate decisions need to be made to avoid losses in the next crop to be grown. When low numbers are present, it is important to take decisions to safeguard future crops. Learning that a paddock is free of nematodes is valuable information because it may be possible to take steps to avoid future contamination. [21]

1.9 Pest status of paddock

1.9.1 Sampling for pre-season pests

Insect pests can seriously reduce plant establishment and populations, and subsequent yield potential.

Common pre-season pests include:

- Desiantha weevil
- cutworms
- false wireworm
- bryobia mites
- balaustium mites
- red-legged earth mites.

Different soil insects occur under different cultivation systems and farm management can directly influence the type and number of these pests:

- Weedy fallows and volunteer crops encourage soil insect build-up
- Insect numbers decline during a clean long fallow due to lack of food
- High levels of stubble on the soil surface can promote some soil insects (i.e. a food source); however, pests may continue feeding on the stubble instead of on germinating crops
- No-tillage encourages beneficial predatory insects and earthworms
- Incorporating stubble promotes black field earwig populations
- False wireworms are found under all intensities of cultivation but decline if stubble levels are very low.

Soil insect control measures are normally applied at sowing. Because different insects require different control measures, the species of soil insects must be identified before planting.

Recognising soil insects

For more information, see Section 7: Insect control.

Detecting soil-dwelling insects

Soil insects are often difficult to detect because they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the moist–dry soil interface.

20 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region. Fact sheet, http://www.grdc.com.au/Resources/Factsheets/2015/03/Root-Lesion-Nematodes

21 DAF Qld (2009) Root lesion nematodes—management of root-lesion nematodes in the northern grain region. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/__data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf

MORE INFORMATION

DAFWA (2016) Identification and control of pest slugs and snails for broadacre crops in Western Australia.

GRDC (2015) Hot Topics: Snail control before seeding.

GRDC (2015) Snail bait application. Fact sheet.

GRDC (2014) Mouse management a numbers game. Ground Cover Issue 111.

GRDC (2015) Surveillance and forecasts for mouse outbreaks in Australian cropping systems. GRDC Update Papers.

GRDC (2012) Mouse control—Western Region. Fact sheet.

For current chemical control options see Pest Genie or APVMA. [22]

1.9.2 Snails

Reports of snail damage are rising in the Western Region with reports from WA growers of snails damaging crops and requiring control—particularly in southern coastal districts and near Geraldton in the northern wheatbelt. [23]

Monitoring regularly, means pests can be detected early, ideally before seeding as there are more control options available at this time. Once the crop has been seeded and germination is commencing, control options are limited to baiting. At this time crops should be examined at night for slug and snail activity.

It is best to look for slugs and snails on moist, warm and still nights. Fresh trails of white and clear slime (mucus) visible in the morning also indicate the presence of slugs or snails. However, prior to and after applying control measures, it is necessary to estimate how many slugs and snails are present.

It is a good idea to monitor in:

- January/February to assess stubble management options for slug and snail management
- March/April to assess options for burning and/or baiting
- May to August to assess options for baiting especially along fencelines
- For snails three to four weeks before harvest to assess risk of snail contamination of grain and if required, implement options to minimise the risk. [24]

See Section 7.9: Pest slugs and snails for more information on snail management.

22 DAF Qld (2011) How to recognise and monitor soil insects. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects

23 J Paterson, 2013. Southern and western snail snapshot. GRDC Ground Cover Supplements 102. https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102/Southern-and-western-snail-snapshot

24 DAFWA (2016) Identification and control of pest slugs and snails for broadacre crops in Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2671

Pre-planting

FAQ

2.1 Varietal performance

2.1.1 Selecting barley varieties

As the number of barley varieties available to growers increases, the decision of which variety to use, come seeding time, has become more difficult. The Barley Variety Guide produced by the Department of Agriculture and Food, Western Australia (DAFWA) and co-funded by Grains Research and Development Corporation (GRDC) provides an independent appraisal of the most relevant barley varieties available to growers in WA. This includes market feedback, grain-yield comparisons, disease-resistance ratings, herbicide tolerance and agronomic attributes. [1]

When selecting a variety, consider crop use, disease prevalence and herbicide tolerance. Select a suitable variety for your planting time and area, taking into consideration yield potential and disease risks. Leaf rust, net blotches and powdery mildew are the more important diseases and selecting a resistant variety can mean improved performance and reliability.

The variety chosen should be:

- appropriate for the environment and farming system
- suitable to the sowing time
- able to be segregated in storage in the case of malting varieties. [2]

Photo 1: *Once at the tillering stage barley is more resilient to pest attack.*

Source: DAFWA

MORE INFORMATION

DAFWA (2016) 2017 Barley variety sowing guide for Western Australia.

GIWA (2016) Western Australian Malting Barley Variety Receival Recommendations 2017/18 Harvest.

GRDC (2015) Using crop competition for weed control in barley and wheat.

GRDC (2015) Barley agronomy results 2014.

GRDC (2014) New and potential malting barley variety update and agronomic developments.

GRDC Crop Variety Guides

1 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

2 P Matthews, D McCaffery, L Jenkins (2014) Winter crop sowing guide 2014. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

2.1.2 Yielding ability and GRDC-funded National Variety Trials (NVT)

When considering a new variety, growers should compare the yield, grain quality and disease resistance with varieties currently grown.

Grains industry productivity is dependent on the continued adoption and deployment of new technologies, including the adoption of new varieties with superior yield and useful disease-resistance characteristics.

National Variety Trials collect the most relevant varieties for each region and test them alongside the elite lines from the breeding programs. For information on the released varieties in the NVT, visit the NVT website at: www.nvtonline.com.au. [3]

Individual trial results from NVT provide only a snapshot in time and may lead to unsuitable varietal choice. Combining data across trials and years increases the chance of selecting the appropriate varieties; the current long-term analysis is based on geographic region. [4]

National focus

In comparison to wheat, individual barley varieties are generally more widely adopted in Australia, often across a wide range of agro-ecological zones. Consequently, barley breeding programs tend to be nationally focused, with national varieties.

In 2012, a collaborative trial series was initiated, involving the Grain Research Development Corporation (GRDC) funded barley agronomy projects operating in the western, southern, and northern grains regions. The trials compared yield and quality responses of potential malt varieties likely to be grown nationally, under a range of management practices.

Eight varieties, selected with a national rather than a regional focus, were sown across nine locations in WA, SA, Victoria and NSW. The varieties selected were Bass⸹, Flinders⸹, Granger⸹, La Trobe⸹, Skipper⸹ and Wimmera⸹, with Buloke⸹ and Commander⸹ included as controls.

Results from this study show that agronomic management (nitrogen (N) application and seed rate) can influence grain yield and quality. The cultivar IGB1101 showed that it was very adaptable, performing well over the range of sites and treatments imposed.

Environmental factors related to growing season rainfall, and climatic conditions during anthesis and grain fill, in combination with soil N status, also impacted on cultivar performance. Grain protein content (GPC) was observed to be highly influenced by environment, exhibiting large genotype by environment interactions.

The study found that apart from some small variations in physical quality parameters (test weight, retention or screenings), GPC was the major factor influencing the failure of cultivars to meet malt receival standards. [5]

Varieties do respond differently to management. The relative performance of varieties is not constant; it changes as the environment changes. Each variety can be successful if their weaknesses are managed for the environment. Growers need to focus on maximising quality or maximising returns rather than focusing on maximising yield when growing malt barley. [6]

3 NVT (2013) Queensland 2013 wheat varieties. GRDC/Department of Agriculture and Fisheries Queensland, http://www.grdc.com.au/NVT-QLD-WheatVarietyGuide

4 A Kelly, A Smith, B Cullis (2013) Which variety should I grow?, GRDC Update Papers, 12 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Kelly-Alison-What-should-I-grow

5 R Graham and B Paynter et al. (2013) Yield and Quality Responses of Potential Malting Barley Varieties of National Significance. 16th Australian Barley Technical Symposium, Melbourne, VIC, 8–11 September 2013, https://www.researchgate.net/publication/274069140_Yield_and_quality_responses_of_potential_malting_barley_varieties_of_national_significance

6 B Paynter (2015) National barley agronomy R&D - focus on V x N x SR interactions. 17th Australian Barley Technical Symposium, Sydney NSW, 13–16 September 2015, https://www.researchgate.net/publication/281853753_National_barley_agronomy_RD_-_focus_on_V_x_N_x_SR_interactions_-_power_point_presentation

2.1.3 Malting and other quality traits

Malting varieties

In WA, to achieve Malt1 specifications, barley growers need to achieve grain protein between 9.5 to 12.5%, in addition to satisfying physical grain quality receival standards, related to grain size, weight and uniformity. [7]

Malting barley varieties in Australia are accredited by Barley Australia. They undergo rigorous testing to ensure they meet malting standards both for domestic and international markets. The Barley Australia website has a list of currently accredited varieties. [8]

Malt barley varieties traditionally account for over 80% of the area sown to barley (Table 1), although in recent years segregated varieties have included the food variety Hindmarsh⌽. Only one feed variety, Mundah, features in the top 10 barley varieties sown in WA. [9]

Malting varieties, in particular, need to be planted, grown and harvested with care. Factors to take into consideration include:

- Phosphorus (P). Too little P will limit yield and increase protein. (WA research shows barley has a similar P requirement to wheat)
- Nitrogen (N). Too little N will reduce yield and quality, whereas excessive N fertiliser can increase screenings and protein levels
- Disease. Appropriate and timely disease management and careful canopy management can improve the chance of achieving malting quality
- Timely weed control. Weeds compete for nutrients and moisture; effective weed control reduces the risk of contamination
- Care with harvest. Avoid skinning the grain; try to minimise weather damage; avoid varietal contamination; use only grain protectants registered for malting barley. [10]

For more information, see: Barley Australia: Preferred varieties list, the DAFWA 2017 barley variety sowing guide for Western Australia and the MyCrop barley app which is also helpful for diagnosis of pest, disease and nutrition.

Table 1: *Grain yield of barley varieties expressed as a percentage of Hindmarsh⌽ (NVT 2005–14). Data presented where there are five or more observations except Rosalind⌽ as only one year of data was available.*

Variety	Agzone 1		Agzone 2		Agzone 3		Agzone 4		Agzone 5		Agzone 6	
	(%)	(no. obs)	(%)	(no. obs)	(%)	(no. obs)	(%)	(no. obs)	(%)	(no. obs)	(%)	(no. obs)
Malt varieties												
Bass⌽	95	8	82	32	94	31	79	11	85	27	96	13
Baudin⌽	85	8	82	32	81	31	76	11	82	27	82	13
Flinders⌽	97	6	94	29	97	27	85	10	93	23	104	11
Granger⌽	100	7	93	32	98	31	82	9	90	27	103	13
La Trobe⌽	103	5	99	25	101	24	97	8	99	20	102	10
Scope CL⌽	94	8	87	32	94	31	85	11	86	27	87	13

7 R Graham and B Paynter et al. (2013) Yield and Quality Responses of Potential Malting Barley Varieties of National Significance. 16th Australian Barley Technical Symposium, Melbourne, VIC, 8–11 September 2013, https://www.researchgate.net/publication/274069140_Yield_and_quality_responses_of_potential_malting_barley_varieties_of_national_significance

8 P Matthews, D McCaffery, L Jenkins (2015) Winter crop sowing guide 2014. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

9 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

10 P Matthews, D McCaffery, L Jenkins (2015) Winter crop sowing guide 2014. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

Variety	Agzone 1		Agzone 2		Agzone 3		Agzone 4		Agzone 5		Agzone 6	
Food varieties												
Hindmarsh$^{\phi}$	100	8	100	32	100	31	100	11	100	25	100	13
Feed varieties												
Compass$^{\phi}$	101	4	98	20	103	20	97	6	98	16	98	8
Fathom$^{\phi}$	97	6	90	29	98	27	93	10	96	24	96	11
Fleet$^{\phi}$	92	8	85	32	95	31	86	11	90	25	90	13
Litmus$^{\phi}$	66	4	88	20	89	20	88	6	80	16	80	8
Lockyer$^{\phi}$	100	8	93	32	98	31	87	11	96	26	103	13
Mundah	73	8	84	29	87	31	88	11	80	27	76	13
Oxford$^{\phi}$	103	7	89	27	96	31	71	9	87	25	108	11
Rosalind$^{\phi}$	-	2	107	11	103	10	104	4	104	8	105	4
Spartacus CL$^{\phi}$	-	2	101	11	98	10	99	4	99	8	101	4
Yagan	-	0	-	0	-	0	-	0	-	0	-	0
Hindmarsh$^{\phi}$ yield (t/ha)	**2.87**	**8**	**2.88**	**32**	**4.42**	**31**	**1.95**	**11**	**3.30**	**25**	**3.17**	**13**

Source: NVT Online nvtonline.com.au

Malting barley purity test

Australia's barley industry has a global reputation as a producer of high-quality malting barley. From a trade perspective it is an enviable reputation, so the GRDC and Diversity Arrays Technology (DArT), one of the world's leading crop DNA profiling laboratories, devised a purity test for malting barley varieties that will ensure our reputation is maintained.

The commercial test, developed with funding from GRDC, helps growers to ensure they are growing malting barley varieties most sought after by maltsters. Malting barley varieties are increasingly more difficult to differentiate. The test can determine the purity of a variety is and which other varieties may be present in a sample. For more information, visit: GrainGrowers Products and Services—Barley testing.

PODCAST

GRDC (2012) New barley test. Driving Agronomy Podcast.

VIDEO

GRDC (2011) Malting Barley Purity GCTV 6. Video.

Food-grade varieties

This is a classification introduced for the 2010 harvest by Barley Australia. Barley varieties need to meet all of the physical quality parameters that apply to accredited malting barleys, such as protein, test weight, screenings and head retention, before they can be accepted into Food Barley segregations. This classification was developed to accommodate Hindmarsh$^{\phi}$, a variety developed to supply maltsters but which failed to gain malting accreditation.

Feed varieties

Feed accredited varieties include any two-row varieties with white aleurone layer. [11]

2.1.4 Disease resistance

Seedling and adult resistance

Leaf disease ratings include both seedling- and adult-stage resistance ratings for the foliar leaf diseases net type net blotch (NTNB), spot type net blotch (STNB), powdery mildew and barley leaf rust (Table 2 and Table 3). There is no seedling data for scald so only the adult-stage resistance is tabulated.

11 GTA (2013) Barley standards. 2013/2014 season. Grain Trade Australia, http://www.grainland.com.au/web/Grainland_Manuals/Product%20Manuals/Grain%20Standards/GTA%20Barley%20Standards%20-%20%202013-14.pdf

Seedling ratings are applicable at early growth stages (two to three-leaf stage) and are important for making decisions on seed fungicide treatments and/or knowing the likely response of a variety if there is early disease pressure. Seedling ratings are also important when assigning varieties to paddocks. Varieties susceptible to stubble-borne diseases like scald, NTNB and STNB are at a high risk of early infection if sown onto one- or two-year-old barley stubble.

Adult plant ratings are applicable at later plant growth stages (after flag leaf emergence) but in some varieties and for some diseases the adult ratings may be applicable as early as stem elongation. Variation in the seedling and adult rating of a variety is most likely due to the presence or absence of adult plant resistance genes.

The ratings of varieties may vary over time and these are noted where observed. Seasonal changes occur because of differences in disease pressure, spread of the disease in the region, changes in climatic conditions, stubble retention and development of new pathotypes. [12]

Table 2: *Seedling (two- to three-leaf stage) leaf disease resistance profiles when grown in WA.*

Disease[1]	Scald	Net type net blotch[4]	Net type net blotch[4]	Spot type net blotch	Powdery mildew[5]	Barley leaf rust6
Pathotype[2]	**Medina**	**Beecher virulent (95NB100)**	**Beecher avirulent (97NB1)**	**(South Perth)**	**(South Perth)**	**(5457 P-)**
Growth Stage[3]	**Seedling**	**Seedling**	**Seedling**	**Seedling**	**Seedling**	**Seedling**
Malt varieties						
Bass⍉	-	MR	S	MRMS	MSS	S
Baudin⍉	-	S	S	MRMS	VS	SVS
Flinders⍉	-	MRMS	S	MS	R	MS
Granger⍉	-	MS	MS	S	R	MS
La Trobe⍉	-	MS	MRMS	S	MSS	MS
Scope CL⍉	-	MR	MR	MS	R	S
Food varieties						
Hindmarsh⍉	-	MRMS	MRMS	SVS	MRMS	S
Feed varieties						
Compass⍉	-	MRMS	S	MRMS	MS	S
Fathom⍉	-	S	S	MR	MS	S
Fleet⍉	-	MSS	MRMS	MR	MRMS	MS
Litmus⍉	-	S	S	S	MS	S
Lockyer⍉	-	MR	MR	S	MS	S
Mundah	-	S	MS	S	SVS	S
Oxford⍉	-	RMR	MR	S	R	S
Rosalind⍉	-	MR	MR*p*	MS	MS*p*	MRMS
Spartacus CL⍉	-	MSS	MSS	SVS	MS	MS
Yagan	-	MRMS	MRMS	MRMS	R	S

Source: Sanjiv Gupta

1. Resistance rating: VS = very susceptible, S = susceptible, MS = moderately susceptible, MRMS = intermediate, MR = moderately resistant, R = resistant, / = due to multiple strains of the pathogen the alternate reaction is also presented, p = provisional rating, - = no data available.

12 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

2. Pathotype: source of disease used in evaluating the disease reaction of the different barley varieties. The source used for evaluating varietal resistance represents the most common pathotype present in WA. On farm reactions of varieties may therefore differ if the pathotype/s present differ to the pathotype used in testing.
3. Growth stage: the seedling resistance score reflects resistance at the two to three leaf stage (data not relevant after four leaf stage). The adult resistance score reflects resistance after flag leaf emergence. Varieties with a VS or S rating at the seedling stage are at a greater risk of early infection. Appropriate cultural (i.e. rotation) and/or chemical (i.e. fungicide) disease management strategies should be considered to minimise the risk when planting those varieties.
4. Net type net blotch: there are two major pathotypes (95NB100 and 97NB1) of NTNB present in WA. The Beecher avirulent (97NB1) pathotype is the dominant isolate, but north of the Great Eastern Highway, Beecher virulent (95NB100) and avirulent (97NB1) pathotypes are present in similar proportions. The reaction of Bass⏀, Compass⏀ and Flinders⏀ as seedlings will differ significantly depending on the pathotype present.
5. Powdery mildew: varieties with a VS or S rating at the seedling stage (Baudin⏀, IGB1334T, Mundah and Rosalind⏀) should be treated with a seed dressing active against powdery mildew to prevent early infection during the tillering stage.
6. Barley leaf rust: a new pathotype (5457 P-) was detected in September 2013 virulent on the Rph3 gene. The resistance score before the / is the seedling resistance in the presence of 5453 P-. The resistance score after the / is the seedling resistance in the presence of 5457 P-. As Bass⏀ and Compass⏀ only carry the Rph3 gene, their seedling and adult resistance in the presence of 5457 P- is reduced. Granger⏀ and Oxford⏀ carry an adult plant resistance gene Rph20.

Disease surveillance

Growers and consultants observing barley varieties carrying significantly greater levels of disease than expected should collect infected material for pathotype identification. These include barley varieties rated as MRMS, MR or R to scald, NTNB, STNB, powdery mildew or barley leaf rust.

Samples of powdery mildew infected leaf material should be forwarded to the Centre for Crop and Disease Management at Curtin University. Unlike other leaf diseases, powdery mildew infected leaves need to be placed into agar to maintain a live culture for pathotyping. To arrange sample collection contact Simon Ellwood via email on simon.elwood@curtin.edu.au and phone +61 (0)8 9266 9915.

Infected scald, NTNB, STNB and barley leaf rust leaf material must be sent in paper envelopes marked with location, variety, disease and date collected. Fold leaf in half so infected area is on the inside. Do not wrap leaf material in plastic or send in plastic lined envelopes.

Scald, NTNB and STNB infected leaf material should be sent to the Department of Agriculture and Food Western Australia, Locked Bag 4, Bentley Delivery Centre WA 6983 and marked attention Jason Bradley. For more information contact Jason Bradley (jason.bradley@agric. wa.gov.au) or phone +61 (0)8 9368 3982.

Barley leaf rust samples should be sent directly to the ACRCP Annual Cereal Rust Survey, Plant Breeding Institute, Private Bag 4011, Narellan NSW 2567. For more information, contact Professor Robert Park (robert.park@sydney.edu. au) or phone +61 (0)2 9351 8806. [13]

Disease rankings

Disease ranking for barley lines and cultivars in NVT is now carried out independently through nationally coordinated projects. A disease-assessment process was implemented for barley in 2012, following the model established for wheat.

13 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

Nationally coordinated NVT disease screenings provide a comparative evaluation of a line's performance under different environments and disease epidemics, giving increased confidence to the disease ratings applied to new varieties. This assists growers in their varietal selection and management decisions and encourages breeding entities to develop varieties with adequate multiple-disease resistance. [14]

For more information See Section 9: Diseases.

Table 3: *Agronomic characteristics of a range of barley varieties when grown in WA. The varieties available to WA growers offer a range of characteristics, allowing growers to chose a variety most suited to their situation.*

Agronomic trait	Coleoptile length[1]	Maturity with late May sowing[2]	Frost risk (floret sterility)[3]	Boron leaf symptoms	Straw strength	Head loss risk[4]	Plant height at maturity[5]	Grain plumpness
Malt varieties								
Bass$^{\phi}$	Medium	Medium	Normal	Medium	Very good	Medium	Short	Good
Baudin$^{\phi}$	Medium	Medium	Normal	Medium	Very good	Low	Short	Fair
Flinders$^{\phi}$	Short	Medium	Lower	Medium	Very good	Low	Short	Mod. good
Granger$^{\phi}$	Medium	Medium	Higher	-	Good	Low	Medium	Mod. good
La Trobe$^{\phi}$	Short	Early	Higher	Medium	Mod. good	Medium	Medium	Mod. good
Scope CL$^{\phi}$	Short	Medium	Normal	-	Fair	High	Tall	Fair
Food varieties								
Hindmarsh$^{\phi}$	Short	Early	Normal	Medium	Fair	Medium	Medium	Mod. good
Feed varieties								
Compass$^{\phi}$	Medium	Medium	Normal	-	Fair	Medium	Medium	Good
Fathom$^{\phi}$	Medium	Medium	Normal	Medium	Fair	Low	Tall	Good
Fleet$^{\phi}$	Long	Medium	Normal	Low	Fair	Medium	Medium	Good
Litmus$^{\phi}$	Short	Early	Normal	Medium	Fair	Medium	Tall	Mod. good
Lockyer$^{\phi}$	Medium	Late	-	Medium	Mod. good	Low	Short	Poor
Mundah	Medium	Very early	Normal	Medium	Fair	Medium	Medium	Very good
Oxford$^{\phi}$	Medium	Late	Higher	-	Very good	Low	Short	Very poor
Rosalind$^{\phi}$	Short	Medium	-	Medium	Good	Low	Medium	Mod. good
Spartacus CL$^{\phi}$	Short	Early	-	Medium	Good	Low	Medium	Mod. good
Yagan	Medium	Very early	-	Medium	Fair	Medium	Medium	Very good

Source: DAFWA

1. Coleoptile length: short (40–60 mm), medium (60–80 mm) and long (80–100 mm).
2. Maturity: very early (–15 to –4 days), early (–3 to +3 days), medium (+4 to +10 days) and late (+11 to +17 days) maturity (days to awn emergence) relative to Stirling when sown in late May. Maturity ranking with a late May sowing differs to the maturity ranking when sown in April or after mid-June.
3. Head loss risk: under adverse conditions barley varieties differ in their risk of shedding. Head loss risk is based on counting heads post-harvest at sites where high levels of head loss has been recorded in high risk varieties.
4. Plant height at maturity: very short (<45 cm), short (45–55 cm), medium (55–65 cm) and tall (65–75 cm) relative to Stirling and Buloke$^{\phi}$ at sites where their straw (ground to base of ear) was between 65–75 cm long. [15]

14 G Hollaway, G Platz (2012) Coordinated disease management. National Variety Trials supplement. GRDC Ground Cover Issue 101, https://grdc.com.au/__data/assets/pdf_file/0020/117191/ground-cover-supplement-101-nvt.pdf.pdf

15 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

MORE INFORMATION

GRDC (2016) Managing frost risk– Northern Southern and Western Regions. Fact sheet.

DAFWA (2009) Bulletin 4765. Maintaining variety purity in the WA malting barley industry.

VIDEO

GCTV 15: Frost Ratings

2.1.5 Frost ratings

Grain growers and their advisers will soon be able to reference Frost Susceptibility Ratings for many varieties of wheat and barley. The ratings are an outcome of the Australian National Frost Program, part of GRDC's Frost Initiative. For more information, see Section 14: Environmental issues.

2.1.6 Agronomic attributes

It can be very difficult to distinguish between varieties once they are sown in the paddock (Table 4).

Some questions about the defining characteristics might include:

- What did the crop look like at eight to ten weeks after seeding (prostrate or erect)?
- Does it have red auricles at the base of the leaf blade where it wraps around the stem?
- Does the head have red awns?
- How long are the awns?
- Is the head near maturity fanned (tapered) or straight (parallel) in shape?
- When you look at the furrow at the germ end of the grain through a magnifying glass, what length is the rachilla (white, rod-shaped organ) and how long are the hairs on the rachis?

If visual cues are not enough, the grain will need to be tested at an accredited laboratory for varietal purity. AGWEST Plant Laboratories offers a mass spectrometry test that compares the protein profile of a combined sample, or 30 individual seeds, or 150 individual seeds.

Grain plumpness

The benchmark malt variety for grain plumpness is Bass$^{\phi}$. All the newer malt varieties have a grain plumpness better than Baudin$^{\phi}$ but not as good as Bass$^{\phi}$. Bass$^{\phi}$ is plumper than Flinders$^{\phi}$ and Granger$^{\phi}$. Plumpness of La Trobe$^{\phi}$ is similar to Hindmarsh$^{\phi}$, whereas Commander$^{\phi}$ is not quite as plump as Hindmarsh$^{\phi}$. Scope CL$^{\phi}$ is slightly plumper than Buloke$^{\phi}$ and similar to Hindmarsh$^{\phi}$.

Grain colour

At grain colour levels of 53-59 'L*', the benchmark malt variety is Baudin$^{\phi}$. Within this range the grain colour of Bass$^{\phi}$ and Flinders$^{\phi}$ is similar to Baudin$^{\phi}$, with Hindmarsh$^{\phi}$ and La Trobe$^{\phi}$ being about 0.5–0.7 'L*' darker and Granger$^{\phi}$ about 1.1 'L*' darker. Below 55 'L*' Commander$^{\phi}$ is similar to Baudin$^{\phi}$, but brighter above 55 'L*'. Scope CL$^{\phi}$ is similar in its grain colour to Hindmarsh$^{\phi}$ and Buloke$^{\phi}$, but is darker than Bass$^{\phi}$ and Baudin$^{\phi}$ below 60 'L*'. [16]

16 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

Table 4: *Visual characteristics of a range of barley varieties when grown in WA. While it can be difficult to determine a barley variety once sown, these visual characteristics can be useful to aid identification.*

Characteristic	Early growth habit	Redness of flag leaf auricle	Redness of awns during grain fill	Awn length	Ear shape	Rachilla length	Rachilla hair length
Malt varieties							
Bass⊕	Prostrate	Present	Weakly present	Long	Parallel	Short-medium	Long
Baudin⊕	Prostrate	Strongly present	Present	Medium	Parallel	Short-medium	Long
Flinders⊕	Prostrate	Strongly present	Present	Medium	Parallel	Medium-long	Short
Granger⊕	Prostrate	Present	Weakly present	Medium	Parallel	Medium	Short
La Trobe⊕	Erect	Present	Present	Medium	Parallel	Medium-long	Short
Scope CL⊕	Semi-erect	Weakly present	Absent	Medium	Tapering	Medium	Long
Food varieties							
Hindmarsh⊕	Erect	Present	Present	Medium	Parallel	Short-medium	Short
Feed varieties							
Compass⊕	Semi-erect	Present	Weakly present	Long	Tapering	Medium-long	Long
Fathom⊕	Erect	Weakly present	Weakly present	Very long	Parallel	Medium	Long
Fleet⊕	Erect	Absent	Absent	Very long	Parallel	Medium-long	Long
Litmus⊕	Erect	Weakly present	Weakly present	Long	Parallel	Medium	Long
Lockyer⊕	Prostrate	Weakly present	Present	Long	Parallel	Medium	Long
Mundah	Erect	Weakly present	Weakly present	Long	Parallel	Medium	Short
Oxford⊕	Prostrate	Present	Present	Long	Parallel	Medium	Long
Rosalind⊕	Erect	Present	Present	Medium	Tapering	-	Long
Spartacus CL⊕	Erect	Absent	Absent	Medium	Parallel	-	Short
Yagan	Erect	Present	Present	-	Tapering	-	Short

Source: DAFWA Bulletin 4765, breeding companies and IP Australia Plant Breeders Rights database pericles.ipaustralia.gov.au/pbr_db/search.cfm

2.2 Varieties

Each of the established, new and future varieties has agronomic (yield, quality, disease, agronomy) strengths and weaknesses. These need to be carefully weighed against demand signals from the market, pricing of malt varieties, pricing of the food variety Hindmarsh⊕, and the location of receival sites. [17]

2.2.1 Malt variety

Bass⊕

Bass⊕ is a medium spring, semi-dwarf, malt barley acceptable for export as grain and as malt but not for shochu. Best suited to environments with a yield potential above 3 t/ha. It has a moderate yield potential combined with good hectolitre weight, high grain plumpness and a high probability of receival as malt barley. Its grain is generally

17 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

0.5% higher in grain protein than varieties such as Baudin$^{\phi}$ and La Trobe$^{\phi}$ at the same yield and high rates of late nitrogen should be avoided. Can show a moderate head loss risk in the Esperance Port Zone, but not in other Port Zones. Fungicides will be required to manage barley leaf rust, STNB, powdery mildew. Weed competitiveness is similar to other semi-dwarf varieties. Target production zones in 2017 are Kwinana-West, Albany and Esperance Port Zones. (InterGrain/Syngenta)

Baudin$^{\phi}$

Baudin$^{\phi}$ is a medium spring, semi-dwarf, malt barley that is acceptable for export as grain, as malt and as a shochu barley. Baudin$^{\phi}$ is still the 'market leader' for the Chinese, south-east Asian and Japanese brewing markets. Best suited to environments with a yield potential above 3 t/ha and where leaf diseases can be promptly sprayed before they reach 5% of leaf area affected. When growing Baudin$^{\phi}$, an integrated disease management plan needs to be implemented as it is susceptible to powdery mildew, NTNB, STNB, and barley leaf rust. Vigorous Baudin$^{\phi}$ crops have reasonable weed competitiveness despite their short height. Target production zone in 2017 is the Esperance Port Zone, whilst niche segregations may be available in Kwinana-West and Albany-North. (Intergrain)

Flinders$^{\phi}$

Flinders$^{\phi}$ is a medium spring, semi-dwarf, malt barley derived from Baudin$^{\phi}$ but with improved resistance to powdery mildew (non-mlo resistance) and barley leaf rust (due to adult plant resistance, Rph20). Flinders$^{\phi}$ is being assessed for export as grain and as malt. Best suited to environments with a yield potential above 3 t/ha. Flinders$^{\phi}$ is a higher yielding option than Hindmarsh$^{\phi}$ and La Trobe$^{\phi}$ in environments with a potential above 5 t/ha (i.e. Agzone 6). Grain plumpness of Flinders$^{\phi}$ is an improvement over Baudin$^{\phi}$, Hindmarsh$^{\phi}$, La Trobe$^{\phi}$ and Scope CL$^{\phi}$ with a grain brightness between Bass$^{\phi}$ and Baudin$^{\phi}$. Fungicides will be required to manage STNB and early infections of barley leaf rust. Weed competitiveness is similar to other semi-dwarf varieties. Target production zones in 2017 are Kwinana West, Albany and Esperance Port Zones. (Intergrain/Syngenta)

Granger$^{\phi}$

Granger$^{\phi}$ is a medium spring, semi-dwarf, malt variety being assessed for export as grain but not as malt or for shochu. Best suited to environments with a yield potential above 3 t/ha. Granger$^{\phi}$ is a higher yielding option than Hindmarsh$^{\phi}$ and La Trobe$^{\phi}$ in environments with a potential above 5 t/ha (i.e. Agzone 6). Granger$^{\phi}$ (like La Trobe$^{\phi}$ and Oxford$^{\phi}$) is more sensitive to frost (higher frost sterility) than other barley varieties. Granger$^{\phi}$'s grain is plumper than that of Baudin$^{\phi}$, but not as plump as Bass$^{\phi}$. Grain brightness is expected to be an issue in coastal areas as it has a naturally darker kernel than other malt varieties. Fungicides will be required to manage scald, STNB and early infections of barley leaf rust. Has durable resistance to powdery mildew (mlo resistance). Target production zones in 2017 are Albany and Esperance Port Zones. (Limagrain/Heritage Seeds)

La Trobe$^{\phi}$

La Trobe$^{\phi}$ is an early spring, semi-dwarf, CCN resistant, malt barley. It is being assessed for export as grain and as malt and for use in the manufacture of shochu in Japan. La Trobe$^{\phi}$ is suited to all environments as a replacement for Hindmarsh$^{\phi}$. Agronomic performance (maturity, weed competitiveness, grain yield, grain plumpness, grain brightness) of La Trobe$^{\phi}$ is almost identical to Hindmarsh$^{\phi}$. It is the most yield responsive malt variety to N. La Trobe$^{\phi}$ (like Granger$^{\phi}$ and Oxford$^{\phi}$) is more sensitive to frost (higher frost sterility) than other barley varieties. Every La Trobe$^{\phi}$ seed should be treated with a good quality smuticide before sowing. Fungicides will be required to manage STNB and barley leaf rust. Target production zones in 2017 are Geraldton, Kwinana, Albany and Esperance Port Zones. (Intergrain/Syngenta)

Scope CL$^{\phi}$

Scope CL$^{\phi}$ is a medium spring, tall height, malt variety suitable for export as grain and as malt but not for shochu. Scope CL$^{\phi}$ is best suited to environments where brome and barley grass are a problem or where there is imidazolinone residues. Scope CL$^{\phi}$'s agronomic response (phenology, disease resistance, weed competitiveness, head loss risk, grain yield and grain quality) is almost identical to Buloke$^{\phi}$. Fungicides will be required to manage STNB and barley leaf rust. It should be harvested when ripe due to a high head loss risk. Scope CL$^{\phi}$ is registered for use with the imidazolinone chemistry herbicide Intervix®. Do not use other imidazolinone herbicides on Scope CL$^{\phi}$. Target production zones in 2017 are Geraldton, Kwinana and Albany Port Zones.

2.2.2 Food variety

Hindmarsh$^{\phi}$

Hindmarsh$^{\phi}$ is an early spring, semi-dwarf, CCN resistant, food barley that is exported to general grade malt markets in China and to Japan for shochu production. Higher yielding than all malt and feed barley varieties (except Compass$^{\phi}$, La Trobe$^{\phi}$, Spartacus CL$^{\phi}$ and Rosalind$^{\phi}$) in environments with a yield potential below 3 t/ha. Above 4 t/ha its yield is often inferior to Flinders$^{\phi}$, Granger$^{\phi}$, Lockyer$^{\phi}$, Oxford$^{\phi}$ and Rosalind$^{\phi}$. Hindmarsh$^{\phi}$ is not as plump as Bass$^{\phi}$, Flinders$^{\phi}$ and Granger$^{\phi}$, but superior to Baudin$^{\phi}$ and Scope CL$^{\phi}$. Grain brightness may be an issue in coastal regions. All seed should be treated with a good quality smuticide before sowing. Fungicides will be required to manage STNB and barley leaf rust. Hindmarsh$^{\phi}$ is likely to be phased out as a segregated variety after the 2017/18 harvest. Target production zones in 2017 are Kwinana-East and Albany Port Zones. (DPI (Vic)/SeedNet)

2.2.3 Feed variety

Compass$^{\phi}$

New medium spring, medium height, CCN resistant, feed barley derived from Commander$^{\phi}$, but with a higher yield potential. Best suited to environments with a yield potential below 4 t/ha. Compass$^{\phi}$ has a similar grain yield potential to Hindmarsh$^{\phi}$, La Trobe$^{\phi}$ and Spartacus CL$^{\phi}$ in Western Australia. Compass$^{\phi}$ is susceptible to lodging, particularly in high yielding situations. Fungicides will be required to manage barley leaf rust. Compass$^{\phi}$ is one of the more weed competitive barley varieties. Undergoing Stage 1 of Barley Australia testing in 2016 with malting accreditation possible in 2018. (University of Adelaide/SeedNet)

Fathom$^{\phi}$

Medium spring, tall height, CCN resistant feed barley. Best suited to environments with a yield potential below 3 t/ha and where there is a high risk of STNB. Similar to or slightly below the grain yield of Compass$^{\phi}$, Hindmarsh$^{\phi}$, La Trobe$^{\phi}$ and Spartacus CL$^{\phi}$. Fungicides will be required to manage early infections of NTNB and barley leaf rust. Fathom$^{\phi}$ has the highest level of resistance to STNB of current varieties. It is mixed for its head colour, having green and waxy green heads. Fathom$^{\phi}$ is one of the more weed competitive barley varieties. (University of Adelaide/SeedNet)

Fleet$^{\phi}$

CCN resistant, medium spring, medium height, feed barley with good overall disease resistance. Fleet$^{\phi}$ is now out-classed as a feed variety and is not recommended for production. Grain yield is generally below Compass$^{\phi}$, Fathom$^{\phi}$, Hindmarsh$^{\phi}$, La Trobe$^{\phi}$, Rosalind$^{\phi}$ and Spartacus CL$^{\phi}$. The hectolitre weight of Fleet$^{\phi}$ is 2-3 kg/hL lighter than Hindmarsh$^{\phi}$ and Lockyer$^{\phi}$ and up to 1 kg/hL lighter than Mundah. It is susceptible to lodging and head loss with early planting. Fleet$^{\phi}$ has a long coleoptile (so can be planted deep) and is suited to both sandy and clayey soils. Fungicides are not likely to be required in low and medium disease risk environments. Fleet$^{\phi}$

is not as competitive against weeds as Compass$^{\phi}$ and Fathom$^{\phi}$. (University of Adelaide/SeedNet)

Litmus$^{\phi}$

Early spring, tall height, feed barley with improved tolerance to low soil pH and high soil aluminium (Al) levels. Best suited to environments with a yield potential below 2 t/ha where the sub-soil (10-30 cm) has a pHCa below 4.8. Carries Alt1 gene which allows its roots to excrete citrate reducing the toxicity of Al in the soil, resulting in increased grain yield relative to traditional barley varieties on acidic soils. Litmus$^{\phi}$ provides growers with an option to diversify their wheat phase on acidic soils, but does not ameliorate the soil. Lime is required to ameliorate soil with a low pH. Litmus$^{\phi}$ has poor straw strength and is susceptible to all leaf diseases. Litmus$^{\phi}$ has been submitted to Barley Australia for evaluation as a malt barley but due to the presence of blue aleurone in its grain its future is uncertain. (InterGrain/Syngenta)

Lockyer$^{\phi}$

Longer seasoned, semi-dwarf, short height, high yielding, feed barley. Best suited to environments with a yield potential above 3 t/ha. Lockyer$^{\phi}$ is higher yielding than Compass$^{\phi}$, Hindmarsh$^{\phi}$ and La Trobe$^{\phi}$ in Agzone 6 and in environments with a yield potential above 4t/ha. Rosalind$^{\phi}$ out-yields Lockyer$^{\phi}$ in all Agzones except Agzone 6. Relative to Oxford$^{\phi}$, Lockyer$^{\phi}$ is able to maintain its grain yield as seeding is delayed into June and July. Fungicides will be required to manage STNB and barley leaf rust. Weed competitiveness has not been tested. (InterGrain)

Mundah

Very early spring, medium height, feed barley. Best suited to environments with a yield potential below 2t/ha and later sowing systems where early season weed control is necessary. Mundah is now outclassed by Fathom$^{\phi}$, Spartacus CL$^{\phi}$ and Rosalind$^{\phi}$. Lower yielding than all the newer feed varieties including Compass$^{\phi}$, Fathom$^{\phi}$, Lockyer$^{\phi}$, Roe and Rosalind$^{\phi}$. Mundah can suffer from severe head loss and lodging. Fungicides are required to manage scald, NTNB (Beecher virulent), STNB, powdery mildew and barley leaf rust. Mundah is one of the more weed competitive barley varieties. (InterGrain)

Oxford$^{\phi}$

Long seasoned, semi-dwarf, short height, feed barley. Best suited to environments with a yield potential above 4 t/ha (i.e. Agzone 6). Oxford$^{\phi}$ performs best with late April or early May planting but its yield potential falls rapidly as seeding is delayed. In those situations, Oxford$^{\phi}$ is often higher yielding than Compass$^{\phi}$, Hindmarsh$^{\phi}$ and La Trobe$^{\phi}$. Rosalind$^{\phi}$ outyields Oxford$^{\phi}$ in all Agzones except Agzone 6. Oxford$^{\phi}$ (like Granger$^{\phi}$ and La Trobe$^{\phi}$) is more sensitive to frost (higher frost sterility) than other barley varieties. Fungicides will be required to manage STNB and early season barley leaf rust. There is evidence of increasing virulence of NTNB and powdery mildew on Oxford$^{\phi}$ barley, mainly in the Stirlings to Coast region. Growers should collect infected leaf samples before spraying with a fungicide. Weed competitiveness is similar to other semi-dwarf varieties. (Limagrain/Heritage Seeds)

Rosalind$^{\phi}$

Rosalind$^{\phi}$ (tested as IGB1302) is a new medium spring, medium height, CCN resistant feed barley derived from Dash and Lockyer$^{\phi}$ with a high grain yield potential. Suited to all environments where there is a low probability of delivering malt grade barley. Rosalind$^{\phi}$, first tested in NVT in 2014, is the new yield benchmark for barley in WA, outyielding Hindmarsh$^{\phi}$ in Agzones 2 to 6 by 3% or more. Has good straw strength and head retention. Fungicides will be required to manage STNB. There is evidence of increased virulence of NTNB on Rosalind$^{\phi}$ barley growing on the south coast. Based on its plant architecture (particularly larger leaf size) Rosalind$^{\phi}$ is expected to have a good level of weed competitiveness, but it has not been tested. (InterGrain/Syngenta)

MORE INFORMATION

DAFWA (2016) 2017 barley variety sowing guide for Western Australia.

DAFWA (2016) Barley variety factsheets.

National Variety Trial Results.

Barley Australia: Varieties handbook.

Paynter, Blakely - Compass and La Trobe head to head from 25 to 400 plantsm² at York in 2014

GRDC (2014) Select the best when saving seed for next years crops. GRDC Media Centre.

Spartacus⫚

Spartacus CL⫚ (tested as IGB1334T) is a new early spring, imidazolinone tolerant feed barley that is agronomically similar to La Trobe⫚. Spartacus CL⫚ plants lack the red anthocyanin pigmentation associated with Hindmarsh⫚ and La Trobe⫚ plants. Has a similar grain yield to Compass⫚, Hindmarsh⫚ and La Trobe⫚ and is higher yielding than Scope CL⫚ in WA. Spartacus CL⫚ is registered for use with the imidazolinone chemistry herbicides Intervix® and Sentry®. Every seed should be treated with a good quality smuticide before sowing. Fungicides will be required to manage STNB and barley leaf rust. In Stage 1 of Barley Australia testing in 2016 with malting accreditation possible in 2018. (InterGrain/Syngenta)

Yagan

Very early spring, medium height, feed barley. Best suited to environments with a yield potential below 2 t/ha or in weed management situations for late sowing or short seasons. Reaches awn peep 12–16 days earlier than Mundah and 14-20 days earlier than Hindmarsh⫚ with late May sowing. As Yagan has not been sown in NVT trials since 2003 there is no current NVT MET data available. Results from DAFWA barley agronomy time of sowing trials suggest that Fleet⫚, Hindmarsh⫚ and Lockyer⫚ are all higher yielding than Yagan. Hindmarsh⫚ also has improved hectolitre weight and grain brightness relative to Yagan. Fungicides may be required to manage scald, STNB and barley leaf rust. Weed competitiveness not tested. (InterGrain) [18]

2.3 Planting seed quality

2.3.1 Seed size

Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if seed is undamaged by insects or harvesting, is stored at suitable temperatures and moisture conditions, and comes from a plant that had adequate nutrition during its growth and grainfilling period. Seed size is also important. The larger the seed, the greater the endosperm and starch reserves. So, although seed size does not alter germination, bigger seeds have faster seedling growth, higher numbers of fertile tillers per plant and potentially higher grain yields. Research in New South Wales in 2008 showed small seed (25.64 g/1,000 seeds) had emergence equal to 90% of that of large seeds (41.31 g/1,000 seeds) when sown at 44 mm depth; however, emergence dropped to 67% when sown at 87 mm, and 53% when sown deep (at 112 mm).

1,000 grain weight

Seed size is usually measured by weighing 1,000 grains to determine the 1,000-grain weight. The 1,000-grain weight varies among varieties and from season to season. Sowing rate needs to vary according to the 1,000-grain weight for each variety, and each season, in order to achieve desired plant densities. Seed grading is an effective way to separate good-quality seed of uniform size from small or damaged seeds and other impurities. [19]

2.3.2 Seed germination and vigour

Seed germination and vigour are highly influential for establishment and yield potential.

Germination begins when the seed absorbs water and ends with the appearance of the radicle. It has three phases:

- water absorption (imbibition)

18 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

19 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

- activation
- visible germination. [20]

Seed vigour includes the properties of the seed that determine the level of activity and performance of the seed during germination and seedling emergence. Losses of seed vigour are related to the reduced ability of seeds to carry out all of the physiological functions that allow them to perform.

This process, called physiological ageing (or deterioration), starts before harvest and continues during harvest, processing and storage. It progressively reduces performance capabilities through changes in cell-membrane integrity, enzyme activity and protein synthesis. These biochemical changes can occur very quickly or more slowly—from a few days to a few years—depending on genetic, production and environmental factors not fully understood. The end point of this deterioration is death of the seed; that is, complete loss of germination.

However, seeds lose vigour before they lose the ability to germinate. That is why seeds that have similar high germination values can differ in their physiological age (the extent of deterioration) and so differ in seed vigour and the ability to perform. [21]

When purchasing seed, request a copy of the germination and vigour analysis certificate from your supplier. For seed stored on-farm, growers can send it to a laboratory for analysis.

A laboratory seed test for germination should be carried out before seeding to calculate seeding rates; however, a simple, on-farm test can be done:

- Use a flat, shallow seeding tray (about 5 cm deep). Place a sheet of newspaper on the base to cover drainage holes and fill with clean sand, potting mix or freely draining soil. Ideally, the test should be done indoors at a temperature of ~20°C or lower. Alternatively, lay a well-rinsed plastic milk container on its side and cut a window in it, place unbleached paper towels or cotton wool in the container. Moisten and place on a window-sill
- Randomly count out 100 seeds. Do not discard damaged ones and sow 10 rows of 10 seeds at the correct seeding depth. This can be achieved by placing the seed on the smoothed soil surface (or alternative medium) and pushing in with a pencil marked to the required depth. Cover with a little more sand or soil and water gently
- Keep growing medium moist but not wet; overwatering will result in fungal growth and possible rotting.
- After seven to 10 days, the majority of viable seeds will have emerged
- Count only normal, healthy seedlings. If you count 78 normal, vigorous seedlings, the germination percentage is 78%. Germination of 80% is considered acceptable for cereals.

The results from a laboratory seed-germination test should be used in calculating seeding rates. [22]

For more information on factors affecting germination, see Section 4: Plant growth and physiology.

Disease

Grain retained for seed from a wet harvest is more likely to be infected with seed-borne disease. It is also more likely to suffer physical damage during handling, increasing the potential for disease.

20 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

21 ISTA Vigour Test Committee (1995) Understanding seed vigour. International Seed Testing Association, https://www.seedtest.org/upload/prj/product/UnderstandingSeedVigourPamphlet.pdf

22 GRDC (2011) Saving weather damaged grain for seed. Northern and Southern Regions. Retaining Seed Fact Sheet, GRDC Jan. 2011, http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC_FS_RetainingSeed2.pdf

Seed-borne disease generally cannot be identified from visual inspection, so it requires laboratory testing. Once a satisfactory germination percentage is known, seed should be tested for diseases including fusarium head blight.

2.3.3 Seed storage

Barley is more susceptible to insect damage in storage than many grains. Germination can be affected by grain temperature, grain moisture content and insect infestation.

Generally, high grain temperatures and high grain-moisture content can cause low germination (<95%). Insect infestation can have a similar effect. Ideally, malting barley would be kept free of insects, and in aerated storage at grain temperatures of 10–20°C with a moisture content <10.5%. However, this is not generally practical and it is important to be aware of the interaction between moisture and temperature (Table 5).

At 20–30°C, short–medium-term storage presents some risk but once the temperature of the grain exceeds 30°C, germination is likely to be affected. Temperatures significantly above 30°C will cause grain to become non-viable.

This applies for drying grain that is required to maintain its germination for malting purposes or as a seed crop. It should be dried slowly at low temperatures.

The moisture of grain in storage will affect its ability to maintain quality over time. The lower the grain moisture, the more stable its storage ability. In practical terms, it is more economical to store grain at ~12% moisture content. [23]

Table 5: *An indication of the interaction between moisture and temperature. The combination of low moisture percentage barley with a storage temperature of 10-20 °C has the greatest potential storage period of between 12 and 18 months.*

Barley moisture %	Storage temperature	Potential storage period
<10.5	10–20°C	Very long, 12–18 months
	20–30°C	Moderate, 6 months
	>30°C	Short, 3 months
10.5–11.5	10–20°C	Long, 12 months
	20–30°C	Moderate, 6 months
	>30°C	Short, 3 months
11.5–12.5	10–20°C	Moderate, 6 months
	20–30°C	Short, 3 months
	>30°C	Very short, <3 months
>12.5	10–20°C	Short, 3 months
	20–30°C	Very short, <3 months
	>30°C	Perhaps 1 month

Source: NSW DPI

A seed is a living organism that releases moisture as it respires. The aim of seed storage is to preserve the viability of the seed for future sowing. The following issues need to be considered:

- Temperature <15°C. High temperatures can quickly damage seed germination and quality
- Moisture <12%. Temperature changes cause air movements inside the silo that carry moisture to the coolest parts of the silo. Moisture is carried upwards by convection currents in the air created by the temperature difference between the warm seed in the centre of the silo and the cool silo walls, or vice versa.

23 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

Moisture carried into the silo headspace may condense and fall back as free water, causing a ring of seed to germinate against the silo wall

- Aeration slows the rate of deterioration of seed if the moisture content is kept at 12.5–14%. Aeration markedly reduces grain temperature and evens out temperature differences that cause moisture movement
- Pest management. Temperature <15°C stops all major grain insect pests from breeding, slowing their activity and resulting in less damage. [24]

MORE INFORMATION

GRDC (2015) Pushing the production barriers. GRDC Update Paper.

GRDC (2015) Local research highlights. GRDC Update Paper.

GRDC (2015) Key outcomes arising from the crop sequence project. GRDC Update Paper.

GRDC (2011) Fertiliser Toxicity. Fact sheet.

VIDEO

GCTV18: Storing planting seed. Video.

2.3.4 Safe rates of fertiliser sown with the seed

Crop species differ in tolerance to N fertiliser when applied with the seed at sowing (Refer to Table 6). Research funded by Incitec Fertilisers has shown that the tolerance of the crop species to ammonium fertilisers placed with the seed at sowing is related to the fertiliser product (ammonia potential and osmotic potential), the application rate and soil characteristics such as moisture content.

Table 6: *Ranking of crop species establishment in their response (1, most tolerant; 6, least tolerant) to ammonia or ammonium applied in close proximity to the seed. Barley is similar to wheat in its tolerance to ammonia or ammonium applied close to the seed but is much more tolerant than canola.*

Winter crop species	Germination	Root length	Shoot length
Barley	2	2	3
Canary seed	4	4	2
Canola	5	5	–
Chickpeas	1	1	–
Wheat	3	3	1

Source: Incitec Pivot

The safest method of applying high rates for fertilisers with high ammonium content is to place them away from the seed by physical separation (combined N–P products) or by pre- or post-plant application (straight N products). [25]

With placement closer to the seed, contact between high concentration solutions and the seedling is more likely.

With no-till practices, seed and fertiliser are often placed close together, which increases the chance of germination being reduced by toxicity. Possibly counteracting this is less disturbance and generally more compact, better moisture-holding soil near the seed, particularly if press wheels are used.

Toxicity levels are highest when seeding into moist, light sands and when seeding in any soil type is followed by a warm dry period.

Experience in WA has shown that fertiliser toxicity in barley is rarely an issue at current fertiliser use rates. [26]

24 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

25 Incitec Pivot Fertilisers (2014) Big N, nitrogen fertiliser placement and crop establishment. Incitec Pivot Ltd, http://bign.com.au/Big%20N%20Benefits/Nitrogen%20Fertiliser%20Placement%20and%20Crop%20Establishment

26 DAFWA (2015) Diagnosing seedling fertiliser damage in cereals. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1986

Planting

Barley is very versatile in its planting time and can be planted relatively early in the season. Preferred planting times are from late April to June but this will vary for each region and variety depending on frosts and seasonal effects.

Early planting in late April to early May will generally produce higher yields, larger grain size and lower protein levels, making barley more likely to achieve malting quality. However, early crops are more likely to have exposure to frost, and growers should assess the frost risk for their area prior to sowing. Late plantings will often mature in hot, dry weather, which can reduce grain size, yield and malting quality. [1]

3.1 Seed treatments

It is critical that all barley seed is treated with a seed pickle that controls smuts and bunts as barley can be quite susceptible to smut and the risk of undeliverable grain is high if seed is untreated. Depending on the yield potential and disease risk, growers may also consider more expensive treatments that also control soil-borne diseases such as Rhizoctonia, foliar diseases and insects. When applying seed treatments, always read the chemical label and calibrate the applicator.

It is important that seed treatments are applied evenly. Seed treatments are best used in conjunction with other disease-management options such as crop and paddock rotation, the use of clean seed, and the planting of resistant varieties.

There are some risks associated with the use of seed treatments. Research shows that some seed treatments can delay emergence by:

- slowing the rate of germination
- shortening the length of the coleoptile, the first leaf and the sub-crown internode.

Any delay in emergence increases exposure to pre-emergent attack by pests and pathogens or to soil crusting, which may lead to a failure to emerge. The risk of emergence failure is increased when seed is sown too deeply or into a poor seedbed, especially in varieties with shorter coleoptiles. [2]

Reduced coleoptile length

In some situations, certain fungicide seed dressings may reduce coleoptile length, which could lead to 'silly seedling syndrome' (leaves grow under soil surface but don't emerge), particularly if short coleoptile varieties or deep sowing are used. Check chemical labels for this information. Coleoptile shortening may also result from use of dinotroaniline herbicides (trifluralin, pendimethalin, oryzalin). Take care where coleoptile-shortening seed dressings are used together with these herbicides, particularly where it is difficult to obtain good depth control of herbicide incorporation and seed placement. [3]

3.1.1 Seed dressings

Seed dressing and in-furrow fungicides contain one or more active ingredients and are marketed under many different trade names. When choosing seed dressing or in-furrow fungicides, consider the range of diseases that could threaten the crop. Consult product labels for registrations, the Australian regulatory database or InfoPest, or see a list of currently registered active ingredients.

1 DAFF (2012) Barley planting, nutrition, harvesting. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

2 Industry & Investment NSW Agronomists (2010) Barley growth & development, PROCROP Series, Industry & Investment NSW. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

3 DAFWA (2016) Seed dressing and in-furrow fungicides for cereals in Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1794

Reassess the disease risk before seeding by looking at seasonal forecasts, green bridge updates and crop disease forecasts for the local area, all available through the Department of Agriculture and Food, Western Australia (DAFWA).

Powdery mildew

Powdery mildew requuires an integrated approach to management which may include choosing varieties with better resistance levels and foliar applications.

If growing a mildew susceptible variety such as Baudin⏀ or Bass⏀, consider treating seed with a product that controls powdery mildew. Failure to do so will allow this disease to build up and possibly mutate allowing it to overcome some of the current fungicides that the industry relies on. Powdery mildew is particularly prone to the development of fungicide resistance. [4]

Loose smut

Smut diseases commonly occur at low levels, but without seed dressings they may increase rapidly and cause significant economic losses to growers. [5]

Air-borne spores of barley loose smut infect the embryo of the forming seed so that, when infected seed is sown in the following year, the tillers of the new plant produce heads that contain spores of loose smut instead of grain, reducing crop yields and continuing the disease cycle.

Seed dressings work by preventing the transmission of disease when the infected seed is grown in the following season so that the head can develop normally.

Even when seed infection levels are high, the most effective seed treatments can reduce this to nearly zero. Field trials in 2013 at Gibson and Wongan Hills WA, found all registered products which were tested reduced loose smut, although the effectiveness varied. [6]

Testing in 2013 of numerous Hindmarsh⏀ barley crops across Southern and Western Australia (WA) showed loose smut infection. In many cases this occurred in spite of treatment with seed fungicides that should have controlled infection. Hindmarsh⏀ it appears, is very susceptible and full label rates and good application is critical to keep infection levels low. Tests are underway at SARDI on infected seed to determine which seed treatments are capable of providing adequate control in Hindmarsh⏀. [7]

Since Hindmarsh⏀ is such a popular variety in WA, inoculum levels of loose smut are relatively high, so seed of all barley varieties needs to be protected against loose smut every year. [8]

DAFWA Diagnostic Laboratory Services (DDLS) can assess the level of seed infection by testing the embryo for presence of the loose smut fungus in seed.

Barley leaf rust

New active ingredient fluxapyroxad (product Systiva®) is now registered as a seed dressing for the control of barley leaf rust. No in-furrow or seed dressing fungicides are currently registered for barley stem rust.

4 H Wallwork (2014) Cereal disease update and use of fungicides on fertiliser and seed. GRDC Update Papers, 27 February 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Cereal-disease-update-and-use-of-fungicides-on-fertiliser-and-seed

5 DAFWA (2016) Seed dressing and in-furrow fungicides for cereals in Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1794

6 DAFWA (2014) Seed dressing key to loose smut control in barley. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3948

7 H Wallwork (2014) Cereal disease update and use of fungicides on fertiliser and seed. GRDC Update Papers, 27 February 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Cereal-disease-update-and-use-of-fungicides-on-fertiliser-and-seed

8 DAFWA (2014) Seed dressing key to loose smut control in barley. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3948

Barley net blotch (net-type and spot-type)

Barley net blotches are more common in medium to high rainfall regions. Net-type and spot-type net blotch can cause more than 30% yield loss in susceptible varieties when grown in previous-season infected stubbles. The primary source of net blotch infection is infected stubbles which spread disease to seedlings but activity against this stubble-borne net blotch has not been demonstrated by many pre-sowing treatments.

Until recently, seed dressings were only registered to control seedborne net-type net blotch, however, seed infection is not considered an important part of the spread of this disease in WA. A new active ingredient fluxapyroxad (product Systiva®) is now registered for both seed borne and stubble borne inoculum of both spot-type net blotch and net-type net blotch. [9]

Rhizoctonia

Rhizoctonia bare-patch is a problem across WA's wheat and barley growing areas and is estimated to reduce WA cereal yields by 1–5% annually at a cost of $27 M. Current management practices in WA are combinations of crop rotation, below seed cultivation along with a fungicide seed-dressing and adequate nutrition. In 2013, new fungicide options became available for application on seed, including Vibrance® and EverGol® Prime and more recently Systiva® has been registered for rhizoctonia. In DAFWA and SARDI field trials, these new seed treatments increased yield by 5% on average in wheat and barley. [10]

3.1.2 Correct seed application is important

Auger and applicator calibration are important to avoid incorrect seed treatment and poor disease control. Incorrect seed treatment may reduce coleoptile lengths or cause other phytotoxic effects on the germinating seedling (over-treated seed). Three steps in the correct application of a seed dressing are to:

- Calibrate the auger grain output: tonnes per hour = weight of a sample (kg) x 3.6 / time (seconds)
- Use a constant auger flow rate during the dressing operation
- Match the amount of seed dressing that is delivered to the auger flow rate.

For example, if the auger is delivering grain at 20 t/hr and the dressing rate is 4 L/t seed, 80 L of dressing will need to be applied per hour or 1.333 L/min. Measure to calibrate the applicator and adjust as required to achieve this rate. [11]

MORE INFORMATION

DAFWA (2016) Controlling barley loose smut in 2016.

FAQ

3.2 Time of sowing

Early sowing will generally produce higher yields, larger grain size and lower protein levels making malt varieties more likely to achieve malt quality. However, early crops are more likely to have exposure to frost and growers should assess the frost risk for their area prior to sowing. Late plantings will often mature in hot dry weather which can reduce grain size, yield and malting quality.

Factors to consider with regard to planting time include:

- Sowing at the right time is critical for optimising grain yield and can also influence grain quality
- Early planting may increase the frost risk, but early-planted crops have the highest yield potential and are more likely to make malting quality
- Planting too early can result in the crop running quickly to head if there is experiences a warm late autumn or warm early winter

9 DAFWA (2016) Seed dressing and in-furrow fungicides for cereals in Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1794

10 D Hüberli, et al. (2014) Liquid banding of fungicide increases yields of cereals in paddocks with rhizoctonia bare-patch. North Mallee Farm Improvement Group Crop Updates 2014, http://researchrepository.murdoch.edu.au/id/eprint/21390

11 DAFWA (2016) Controlling barley loose smut in 2016. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3906

- Later maturing and shorter stature varieties are preferred for early planting to avoid tall lush early growth
- At flowering, barley can tolerate a frost better than wheat (approx. 2°C) because most of the flowering occurs in the boot
- Recent experience has shown that barley is most susceptible to frost during grain fill
- Hot and dry weather during spring can reduce the grain-fill period and affect yield and grain size, particularly if night temperatures do not fall below 15°C
- Later planting and later flowering generally result in declining yield potential due to higher temperatures and moisture stress during flowering [12]

Variable autumn/winter rainfall can delay the ability to sow in the optimum sowing window due to insufficient moisture for seed germination near the soil surface. Growers are increasingly sowing early for timeliness of operation, and are willing to risk sowing into dry topsoil and wait for rain rather than sow deep into a moisture band and risk losses in establishment and early vigour. [13]

MORE INFORMATION

GRDC (2013) Final report: Dry Seeding into crop residues in the WA Wheat-Belt.

Effect of delayed sowing

Research in WA in 2012–13 revealed the general impact of delayed sowing on malt and food varieties was to decrease early biomass, plant height, lodging risk, and grain yield whilst increasing screenings, grain protein concentration and grain brightness.

Delayed sowing (3–4 weeks) increased the risk of delivering feed grade barley, primarily due to high screenings and high grain protein.

In the study, delayed seeding occasionally influenced the response to seed rate, but there was no evidence to suggest the target density should be changed if the target seeding date is delayed by 3–4 weeks. [14]

Sowing date responses

Development or time to flower in barley is controlled by temperature and daylength. Barley is known as a 'long day' plant, as its development is often inhibited under shorter days (daylength less than 16 hours). Cultivars differ in their response to sowing date because of differences in the duration of their basic vegetative phase and their daylength length sensitivity.

Basic vegetative period (BVP) is the minimum number of leaves formed on the mainstem when a plant has had its vernalisation response satisfied and is grown in a daylength above 16 h. BVP modifies the plant's response to temperature and daylength.

Daylength sensitivity (DLS) is a measure of the sensitivity of a cultivar to daylength and reflects the responsiveness of a cultivar to a change in sowing date. DLS insensitive cultivars will form the same number of leaves on the mainstem, regardless of sowing date. The final leaf number on DLS sensitive cultivars, however, will differ due to sowing date.

Vernalisation response (VRN) is a measure of the responsiveness of a cultivar to a certain number of 'cold' hours needed to initiate its development. All barley cultivars currently grown in WA are spring types and as such have little or no vernalisation requirement.

La Trobe⁽ᴾ⁾/Hindmarsh⁽ᴾ⁾ is a dominant barley cultivar in WA due to its good agronomic adaptation to most locations and sowing dates due to a phenology based on a short BVP and a high DLS. It has however been demonstrated that varieties with medium BVP and moderate DLS or with long BVP and mild DLS are better suited to earlier

12 DAFF (2012) Barley planting, nutrition and harvesting. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

13 Hart Field Site Group Inc. (2013) The 2013 Hart Trial Results, http://www.hartfieldsite.org.au/media/2013%20TRIAL%20RESULTS/2013_Hart_Trial_Results_Book.pdf

14 B Paynter, A Hills, R Malik. (2016) How much is the seed rate (changing from 50 to 400 plants/m^2) response of barley influenced by date of seeding? GRDC Grains Research Updates, 29 February–1 March 2016, http://www.giwa.org.au/2016researchupdates

MORE INFORMATION

2017 Barley variety guide for Western Australia.

DAFWA (2016) Frost: tools & support.

GRDC, (2016) Managing Frost Risk. GRDC Publications

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

GRDC (2016) East West Sowing. Driving Agronomy Podcast.

UWA (2014) Sow west young man.

sowing opportunities than La Trobe⍉. Varieties with short BVP and high or very high DLS have adapted to both early and late sowing dates.

There is a lot of interest in early sowing (before 05 May) but there is very little data to support decisions on which barley cultivar to sow. An understanding of the duration to flowering is useful in determining the risks of frost and heat stress as well how different cultivars respond to early sowing versus later sowing. [15]

Frost risk

Frost damage to crops late in the growing season has been identified as a major constraint impacting on grower productivity and profitability in WA's central and southern grainbelt.

Growers are facing increased risk of grain losses from more severe, frequent, prolonged and/or unseasonal frost events, and a widening of the frost event window in late winter and spring. [16]

Frost management strategies include:

- thermal imaging, which has identified a 3–4°C difference in minimum temperatures between paddocks, guiding where frost sensitive varieties are planted
- planting frost-prone paddocks last to help avoid the high-risk frost period
- using paddock records to monitor frost history
- managing frost risk by growing more hay, pasture or oats on high risk paddocks
- reducing inputs in high risk paddocks to limit financial and agronomic exposure. [17]

In addition, identifying and compiling zones and/or maps that show the range of frost susceptibility of paddocks will enable growers to adopt diverse or alternative agronomic practices to spread production and financial risk.

New tools to spatially assess frost risk and pinpoint crop damage rapidly and accurately are being tested to improve understanding of frost and fine-tune farm-scale responses. Data generated from these sources in paddock zoning and planning, along with other precision agricultural data such as topographic, electro-magnetic and yield maps; temperature monitors; and the grower's own experiences will help to manage frost. [18]

For more information, see Section 14.1: Frost.

Orientation

Switching the orientation of crop planting to east–west can more effectively 'shade out' weeds in the inter-row than using a north–south orientation. In southern Australia, if crops are sown east–west, at a right angle to the sunlight direction, the sun's rays hit the crop row and shade the weeds in the inter-row.

Trials indicate that sowing in this direction means 10–20% less sunlight hits the inter-row during winter, reducing soil temperature and significantly suppressing weed growth, biomass and seed set.

There was not a significant yield difference in the crops sown east–west compared to north–south at these sites, but weed burdens were much lower. [19]

15 B. Paynter (2015) Seasonal and genetic differences in the phenology (duration to awn emergence) of barley when sown in late April through to early July. WA Agribusiness Crop Updates, 24–25 February 2015, http://www.giwa.org.au/pdfs/CR_2015/Paynter_Blakely_Seasonal_and_genetic_differences_henology_of_barley_when_sown_in_late_April_FINAL.pdf

16 GRDC (2016) Managing Frost Risk. Case studies of growers in Western Australia. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2016/07/rcsn-kwinanaeast-managingfrostrisk-casestudies

17 GRDC (2014) Frost management high on western cropping agenda. Ground Cover, Issue 109, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109

18 GRDC (2016) Managing Frost Risk. Case studies of growers in Western Australia. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2016/07/rcsn-kwinanaeast-managingfrostrisk-casestudies

19 GRDC (2016) Getting the right angle on crop competition. Ground Cover, Issue 125, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-125-NovemberDecember-2016/Getting-the-right-angle-on-crop-competition

3.3 Targeted plant population

Plant population is influenced by seeding rate, row spacing and emergence percentage. Emergence percentage is calculated as the number of seedlings (counted at the second leaf stage) divided by the number of seeds sown per square metre. Target plant populations vary with yield potential, seasonal conditions and sowing date.

Barley is able to compensate for lower than ideal plant populations, to some degree, by increasing tiller numbers. However, targeting plant population at sowing makes the most efficient use of water and nutrients. To reach a target plant population for the environment and seasonal conditions, adjust sowing rates to allow for:

- yield potential—use higher rates with increased yield potential
- soil moisture—use higher rates if dry sowing or marginal moisture
- sowing date
- seed germination percentage
- seed size
- seedbed condition [20]

3.3.1 Seeding rate

Seeding rate is the amount (in kg) of seed needed to plant in order to establish the target plant population.

The recommended number of established plants per m² for food and malt varieties is 120 plants/m² for Baudin⚲, Commander⚲, Granger⚲ and Scope CL⚲, which are quite sensitive to establishment density. Bass⚲, Flinders⚲, Hindmarsh⚲ and La Trobe⚲ are more flexible in their target density and can be sown at between 150–180 plants/m², however sowing less plants may reduce profit. All feed barley varieties should be sown at more than 180 plants/m².

The number of seed per kg will vary depending on variety and the season in which the seed was produced. This varies from season to season.

Lower rates should be used when there is limited subsoil moisture at sowing, and in drier areas. In these areas high seeding rates tend to decrease grain size and increase screenings in barley.

Research by the DAFWA barley agronomy team found that increasing the seed rate of barley will significantly decrease the quality of barley crops in medium to high rainfall areas.

The target seed rate in kilograms per hectare differs between varieties due to kernel weight and response to increasing plant density.

In 2013, surveys carried out by the research team found just 15% of growers counted the number of established plants per metre to determine the plant density in their paddocks and potential yield from this density. In order to optimise production growers should count their establishment (per m²) to know if they are hitting their targets. [21]

3.3.2 Calculating sowing rate

Sowing rate can be calculated by knowing the seed weight, germination percentage and the required plant density. For example: barley seed with a seed weight of 4.5 gm/100 seeds, germination percentage of 95 per cent and a required plant density of 170 plants/m² = 4.5 x (10/95) x 170 = 80.5 kg/ha. [22]

MORE INFORMATION

DAFWA (2016) What is the optimum seed rate for your barley variety?

Paynter, Blakely et al - How much is the seed rate response: http://www.giwa.org.au/_literature_209962/Paynter,_Blakely_et_al_-_How_much_is_the_seed_rate_response

Paynter, Blakely et al - How much does seed rate influence barley's performance: http://www.giwa.org.au/_literature_210322/Paynter,_Blakely_et_al_-How_much_does_seed_rate_influence_barley%E2%80%99s_performance

20 Industry & Investment NSW Agronomists (2010) Barley growth & development, PROCROP Series, Industry & Investment NSW. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

21 DAFWA (2016) What is the optimum seed rate for your barley variety? Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/5375

22 Agriculture Victoria (2012) Growing wheat. Note: AG0548, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat

Crop establishment

Establishment in the field can be affected by a number of factors such as:

- seedbed moisture
- germination and vigour of the seed
- seed treatments and herbicides reducing coleoptile length
- seed–soil contact
- high temperatures
- disease
- soil insects and soilborne diseases
- depth of planting (may be inaccurate or variable).

The impact of poor establishment and seedling vigour will be lessened if seedbed requirements are matched to machinery capabilities and seed quality. [23]

3.3.3 Plant population

To check the plant population in a cereal crop.

Cut to size a 1-m length of steel rod or wooden stick. While the crop is still young, preferably no later than day 20 after sowing (to identify individual plants easily), place the 1-m rule along a row and count the number of plants along this row. Do this 10 times at different locations to get a representative count, and calculate the average.

An establishment rate of 70% means that for every 10 seeds planted, only seven will emerge to produce a plant. A planting rate to achieve 700,000–1,000,000 plants/ha is normally in the range 30–50 kg seed/ha. [24]

Research update

The target establishment densities for sowing malt barley in WA are 120 to 150 plants/m^2.

A GRDC-funded study by DAFWA in 2013–14 evaluated 12 barley varieties for their response to four different seed rates (50, 100, 200 and 400 plants/m^2) at eight locations (Wongan Hills, Merredin, Cunderdin, York, Katanning, Kojonup-W, Wittenoom Hills and Grass Patch).

The study found sowing more than 300 plants/m^2 did not cause a grain yield penalty.

On average increasing the seed rate from:

- 50 plants/m^2 (20 to 30 kg/ha) to 100 plants/m^2 (45 to 65 kg/ha) increased grain yield by 10 ± 1%
- 100 plants/m^2 to 200 plants/m^2 (90 to 130 kg/ha) increased it by a further 4 ± 1%
- 200 plants/m^2 to 400 plants/m^2 (seed rate of 205 to 295 kg/ha) resulted in another 1 ± 1% yield gain.

However, sowing barley to establish 50 plants/m^2 (20 to 30 kg/ha) came with a yield penalty of at least 10% compared to sowing more than 100 plants/m^2 (seed rate of >45 kg/ha).

The optimum plant population for grain yield in the study was 137 ± 9 plants/m^2.

Feed barley growers should establish more than 150 plants/m^2, and in paddocks with a high weed burden, aim for target establishment densities above 200 plants/m^2 (90 to 130 kg/ha) depending on seed weight and germination per cent. [25]

23 P Keys, AM Bach (2010) Plant population for Queensland. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/plant-population

24 NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries 2007, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

25 B Paynter, A Hills, R Malik (2016) How much does seed rate (changing from 50 to 400 plants/m^2) influence barley's performance? GRDC Grains Research Updates, 29 February–1 March 2016, http://www.giwa.org.au/2016researchupdates

3.4 Row spacing

The traditional row spacing in much of WA has been 18 cm for cereals, but greater adoption of no-till farming systems has increased interest in wider row spacing such as 30 to 50 cm depending on the crop type and region.

The most appropriate row spacing is a compromise between crop yield, ease of stubble handling, optimising travel speed, managing weed competition and soil throw and achieving effective use of pre-emergent herbicides. Although row spacing is a relatively simple thing to change, the effect on the whole farm system can be complex and can influence yield, time of sowing, machinery, herbicide, and seed and fertiliser costs, as well as the types of crops sown.

The impact of row spacing on cereal yield varies depending on the growing season rainfall, the time of sowing and the potential yield of the crop. The higher the yield potential, the greater the negative impact of wider rows on wheat and barley yields.

Trials with high yielding barley crops, where the average yield was more than 3t/ha (range 2.7 to 3.4 t/ha) found doubling row spacing from 18 to 36 cm and from 25 to 50 cm resulted in yield penalties in the order of 0.7 t/ha. [26]

3.5 Sowing depth

Sowing depth is the key management factor for uniform rapid emergence and establishment. Factors to consider include:

- The ideal depth to sow barley is 20 to 30 mm, depending on the availability of moisture and the variety
- Depth is particularly important in varieties with short coleoptiles
- Sowing depth influences the rate of emergence and the percentage of seedlings that emerge
- Deeper seed placement slows emergence; this is equivalent to sowing later
- Seedlings emerging from greater depth are also weaker and tiller poorly. [27]

IN FOCUS

3.5.1 Barley Varieties Differ in Coleoptile Length and Emergence from Deep Sowing[28]

An ability to establish well under a range of seedbed conditions is desirable in cereal varieties. Moisture-seeking, heavy stubble residues, rain between seeding and emergence and the requirement to avoid soil-applied pre-emergent herbicides can result in the need for plants to establish from a greater than ideal depth. This study measured the emergence of up to twelve Australian barley varieties from three seeding depths in the field in three seasons. The effects of seed size and seed-applied fungicide were also determined.

Deeper seeding reduced the rate and the number of plants which emerged and there were large differences among varieties in final emergence. Emergence was related to coleoptile length and not to plant height. Seed treatment with triadimenol reduced emergence, particularly with deeper seeding, and the size of this reduction differed among varieties. These results emphasise the need to sow varieties that have

26 GRDC (2011) Crop Placement and Row Spacing, Western Region. Fact sheet, https://grdc.com.au/Resources/Factsheets/2011/02/Crop-Placement-and-Row-Spacing-Western-Fact-Sheet

27 Industry & Investment NSW Agronomists (2010) Barley growth & development, PROCROP Series, Industry & Investment NSW. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

28 Pers comms N A Fettell. Agricultural Research & Advisory Station, Condobolin, University of New England.

short coleoptiles at shallow depths and to take care with seed grading and the use of seed dressings.

Seeding depth responses

An ability to establish well under a range of seedbed conditions is desirable in cereal varieties. Moisture-seeking, heavy stubble residues, rain between seeding and emergence and the need to avoid pre-emergent herbicides can result in the need for plants to emerge from greater than ideal depth.

Twelve barley varieties were sown at three depths (44, 87, and 112 mm of soil above the seed) at Condobolin in Central West NSW in 2008, using seed from a common 2007 site. Seed was graded into three sizes and was untreated except for one lot of medium-size seed which was treated with the higher registered rate of triadimenol. Emergence results are shown in Figure 1.

Deeper sowing reduced emergence in all varieties. At 87 mm, the reduction was greatest in Buloke⁽ᴾ⁾, Gairdner and Fitzroy (average 57% emergence) and least for Fleet⁽ᴾ⁾ and Commander⁽ᴾ⁾ (73%). At 112 mm, there was a similar pattern with Buloke⁽ᴾ⁾, Gairdner, Fitzroy and Hindmarsh⁽ᴾ⁾ the poorest (40%) and Fleet⁽ᴾ⁾ the best (64%). Emergence was related to coleoptile length and not to plant height. Buloke⁽ᴾ⁾, a tall variety, has a short coleoptile and emerged poorly from depth whereas Baudin⁽ᴾ⁾, a semi-dwarf variety, emerged well from depth.

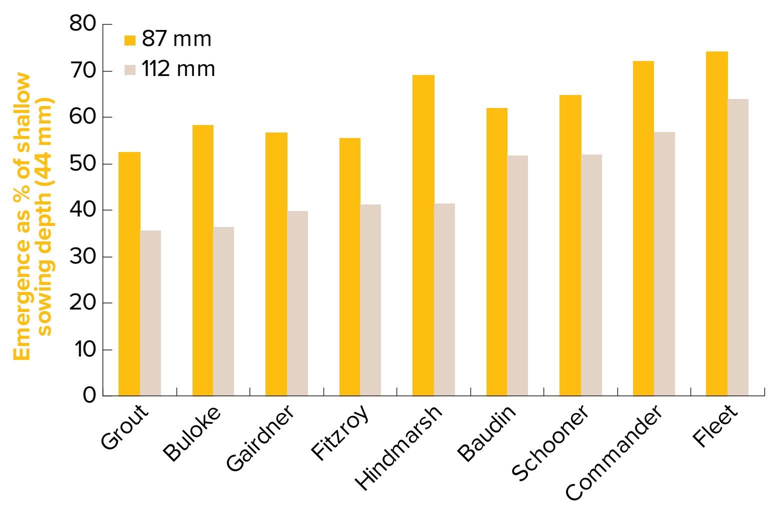


Figure 1: *All barley varieties had greater levels of emergence at 87mm than 112mm however the difference between depths varied between varieties. Plant emergence for medium (87 mm) and deep (112 mm) sowing, as a percentage of the emergence from shallow (44 mm) sowing, 2008.*

Source : UNE

The experiment was repeated in 2009, using seed from a common 2008 site, but without the three seed size treatments. Sowing depths (thickness of soil above the seed) were 52, 77 and 101 mm, and soil moisture content remained high (with no crusting) throughout the establishment period. Emergence results are shown in Figure 2. Deeper sowing reduced emergence in most comparisons, although the reductions were generally less than in 2008, possibly because the sowing depths were closer together. At both 77 and 101 mm, Fleet⁽ᴾ⁾ showed the least reduction in emergence, followed by Buloke$^{\phi}$, Commander$^{\phi}$ and Schooner. Hindmarsh$^{\phi}$ and Grout showed the poorest emergence, particularly from 101 mm. The variety responses were generally similar to 2008 with the exception of Buloke$^{\phi}$, which performed much better in 2010.

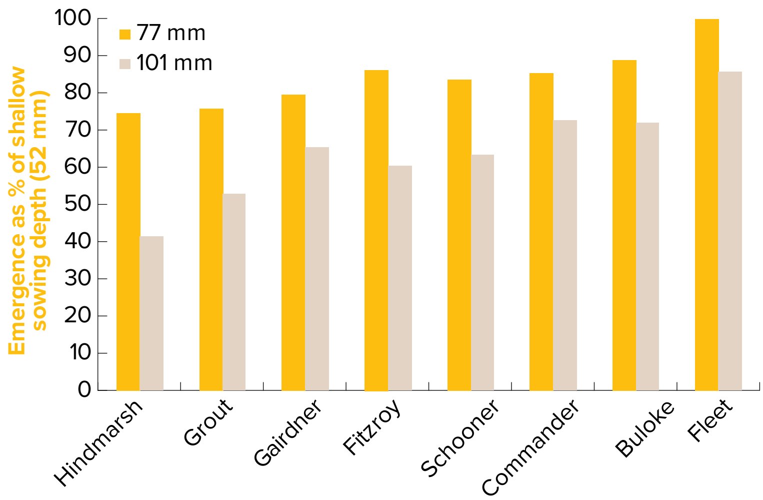


Figure 2: *Plant emergence for medium (77 mm) and deep (101 mm) sowing, as a percentage of the emergence from shallow (52 mm) sowing, 2009.*

Source : UNE

Seed treatment with triadimenol suppressed emergence in all varieties in 2008 (Figure 3), particularly at deeper sowing depths, in line with its known effect of shortening coleoptile length. The effect of triadimenol was greatest where varieties with short coleoptiles were sown at 87 or 112 mm, resulting in emergence values only 20–40% of those for untreated seed.

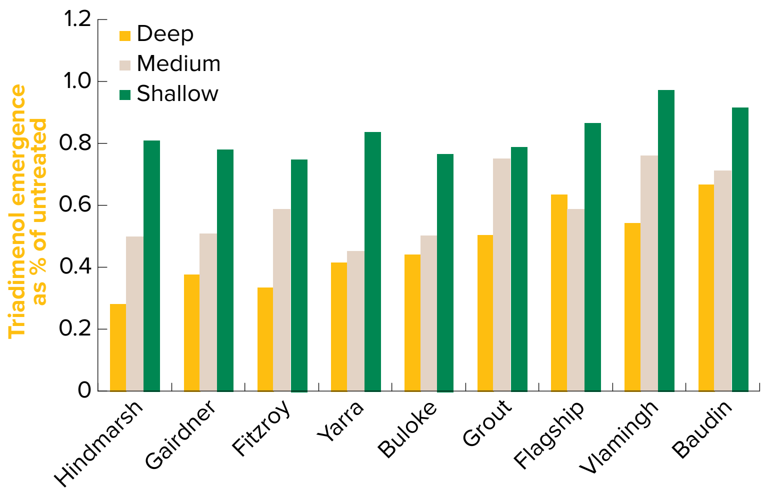


Figure 3: *Plant emergence of triadimenol treated seed as a percentage of the emergence of untreated seed, compared at shallow (44 mm), medium (87 mm) and deep sowing (112 mm) in 2008.*

Source : UNE

Triadimenol also reduced emergence in 2009, but the effect was much smaller than in 2008, particularly with deeper sowing (Figure 4). Averaged over 12 varieties, triadimenol reduced emergence by 11% at the two shallower depths and 19% with deep sowing.

Overall, these results emphasise the need to sow varieties that have short coleoptiles at shallow depths and to take care with seed grading and the use of seed dressings.

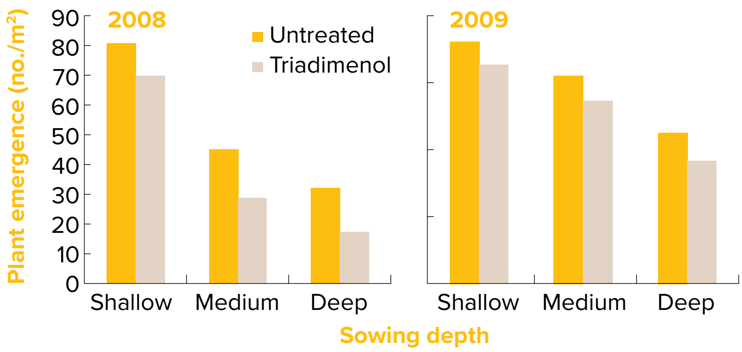


Figure 4: *Plant emergence from untreated and triadimenol-treated seed, averaged over 12 varieties, in 2008 and 2009.*

3.6 Sowing equipment

The incorporated by sowing (IBS) application technique seems to be the safest way of using most residual and pre-emergent herbicides, as the seed furrow is left free of high concentrations of herbicide. The soil from that furrow is thrown on the inter-row. In-furrow weed control is generally achieved by crop competition and/or small amounts of water-soluble herbicides washing into the seed furrow. For this reason, best results in IBS application are when water-soluble herbicides are used either solely or in conjunction with a less-soluble herbicide.

Because of the furrow created by most no-till seeders, post-sowing pre-emergent (PSPE) applications of many herbicides are not ideal and are usually not supported by labels, as the herbicides can concentrate within the seed furrow if washed in by water and/or herbicide-treated soil. For volatile herbicides that need incorporation following application, PSPE is not a viable option.

Tine seeders

Tine seeders vary greatly in their ability to effectively incorporate herbicides. There are many tine shapes, angles of entry into the soil, break-out pressures, row spacings and soil surface conditions. Each of these factors causes variability in soil throw, especially when combined with faster sowing speeds (>8 km/h). Consequently, herbicide incorporation is variable between seeders.

A common rule of thumb is in WA is that tine seeders with knife points and press wheels can operate at 1 km less than the numbers of inches of row spacing (e.g. 8 inch row spacing = 7 km/hr)

Agronomist's view

Disc seeders

Disc machines show similar variability in their ability to incorporate herbicides. Disc angle, number of discs, disc size, disc shape, sowing speed, closer plates and press wheels all have an impact on both soil throw and on herbicide-treated soil returning into the seed furrow. Some discs can throw enough soil for incorporation of herbicides such as trifluralin.

In all cases with tines and discs, crop safety is usually enhanced by applying herbicides IBS rather than PSPE.

Knife points and harrows cause a lot of herbicide-treated soil to return into the seed furrow and are therefore not ideally used in IBS application. Knife points and press wheels do a much better job. [29]

Seeder calibration is important for precise seed placement, and seeders need to be checked regularly during sowing.

Irrespective of the disc seeder, research in southern NSW has clearly shown that a well set-up tine seeder will offer greater crop safety than a well set-up disc seeder. This is mostly because a knife point and press wheel will place more soil on the inter-row, minimising the amount of herbicide-treated soil washing into the seed furrow. Soil throw in tines is also better controlled, resulting in less herbicide-treated soil in a typically wider furrow.

This research has also demonstrated that some herbicides and rates of a particular herbicide are better suited to a disc-seeder system. For example Sakura® and Boxer Gold® are much better suited to disc systems rather than trifluralin. [30]

MORE INFORMATION

GRDC (2011) Stubble Management. Fact sheet.

GRDC (2015) Seeding systems and pre-emergence herbicides. GRDC Update Papers.

GRDC (2013) Disc seeders and pre-emergence herbicides. GRDC Update Papers.

29 B Haskins (2010) Residual herbicides at sowing using disc and tyne no till seeding equipment., GRDC Update Papers.

30 B Haskins (2012) Using pre-emergent herbicide 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

Plant growth and physiology

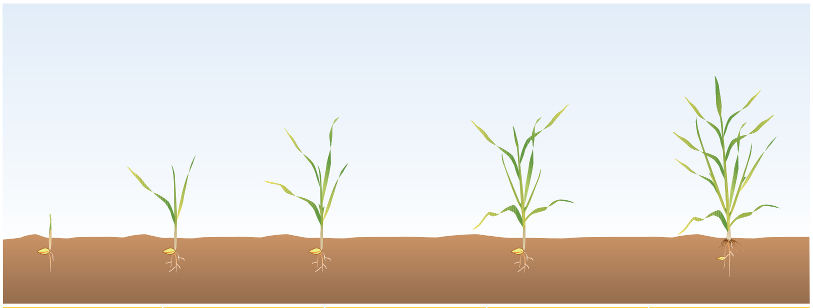
4.1.1 Plant growth stages

A growth-stage key provides farmers, advisers and researchers with a common reference for describing the crop's development.

4.1.2 Zadoks Cereal Growth Stage Key

Zadoks Cereal Growth Stage Key (Figure 1) is the most commonly used key to growth stages for cereals, in which the development of the cereal plant is divided into ten distinct development phases covering 100 individual growth stages. Individual growth stages are denoted by the prefix GS (growth stage) or Z (Zadoks), for example, GS39 or Z39.

The principal Zadoks growth stages used in relation to disease control and N management are those from the start of stem elongation through to early flowering: GS30–GS61.



Zadoks Growth Stage	GS 00-09	GS10-19	GS20-29	GS30-39	GS40-49
Development phase	Germination	Seedling growth	Tillering	Stem elongation	Booting

Zadoks Growth Stage	GS 50-59	GS60-69	GS70-79	GS80-89	GS90-99
Development phase	Ear emergence	Flowering	Milk development (grain fill period)	Dough development (grain fill period)	Ripening

Figure 1: *Zadoks growth stages.*

Source: GRDC

Table 1: *Zadoks decimal growth scale for cereals*

Code	Stage
Germination	
00	Dry seed
01	Start of imbibition
03	Imbibition complete
05	Radicle emerged from seed
07	Coleoptile emerged
09	Leaf just at coleoptile tip
Seedling growth	
10	First leaf through coleoptile
11	First leaf unfolded
12	2 leaves unfolded
14	4 leaves unfolded
16	6 leaves unfolded
18	8 leaves unfolded
Tillering	
20	Main shoot only
21	Main shoot & 1 tiller
22	Main shoot & 2 tillers
24	Main shoot & 4 tillers
26	Main shoot & 6 tillers
28	Main shoot & 8 tillers
Stem elongation	
30	Stem starts to elongate (head at 1 cm)
31	1st node detectable
32	2nd node detectable
34	4th node detectable
36	6th node detectable
37	Flag leaf just visible
39	Flag leaf/collar just visible
Booting	
41	Flag leaf sheath extending
43	Boot just visibly swollen
45	Boot swollen
47	Flag leaf sheath opening
49	First awns visible
Head emergence	
50	1st spikelet of head just visible
53	1/4 of head emerged
55	1/2 of head emerged
57	3/4 of head emerged
59	Emergence of head complete
Anthesis (flowering)	
61	Beginning of anthesis
65	Anthesis 50%
69	Anthesis compete
Milk development	
71	Seed watery ripe
73	Early milk
75	Medium milk
77	Late milk
Dough development	
83	Early dough
85	Soft dough
87	Hard dough
Ripening	
91	Seed hard (difficult to divide by thumbnail)
92	Seed hard (can no longer be dented by thumbnail)
93	Seed loosening in daytime
94	Overripe, straw dead & collapsing
95	Seed dormant
96	Viable seed giving 50% germination
97	Seed not dormant
98	Seed dormancy induced

Early stem elongation GS30–33

To ensure the correct identification of these growth stages, plant stems are cut longitudinally so that internal movement of the nodes (joints in the stem) and lengths of internodes (hollow cavities in the stem) can be measured.

Leaf dissection at GS32 and GS33

This is a method for determining which leaves are emerging from the main stem prior to the emergence of the flag leaf. Knowing which leaves are present is critical if fungicide use is to be optimised to protect leaves.

The Zadoks Cereal Growth Stage Key does not run chronologically from GS00 to GS99; for example, when the crop reaches three fully unfolded leaves (GS13), it begins to tiller (GS20) before it has completed four, five and six fully unfolded leaves (GS14, GS15, GS16).

It is easier to assess main stem and number of tillers than it is the number of leaves (owing to leaf senescence) during tillering. The plant growth stage is determined by main stem and number of tillers per plant; for example, GS22 is main stem plus two tillers and GS29 is main stem plus nine or more tillers.

In Australian cereal crops, plants rarely reach GS29 before the main stem starts stem elongation (GS30). Because of growth stages overlapping, it is possible to describe a plant with several growth stages at the same point in time. For example, a cereal plant at GS32 (second node on the main stem) with three tillers and seven leaves on the main stem would be at GS32, 23 and 17, yet practically, it would be regarded as GS32, because this describes the most advanced stage of development.

Note: After stem elongation (GS30), the growth stage describes the stage of the main stem; it is not an average of all the tillers. This is particularly important with timing fungicide, for example GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged. [1]

For more information, download the GRDC guide: Cereal growth stages.

MORE INFORMATION

http://www.nvtonline.com.au/wp-content/uploads/2013/02/Zadoks-Growth-Scale.pdf

4.1.3 Maturity

The maturity, or length of time taken for a variety to reach flowering, depends on vernalisation, photoperiod and thermal-time requirements. Recommended sowing times are decided by assessing the maturity of varieties in different environments and with different sowing times.

After grainfilling, the vascular system supplying the grain with water and nutrients is blocked and the grain stops growing and turns brown. This is physiological maturity. The mature barley grain comprises mainly starch (75–85%), protein (~9–12%) and water (~8–12%). [2]

Physiological maturity occurs between 40 and 50 days after flowering. When maximum grain dry weight is achieved in the field, the loss of green colour from the glumes and peduncle is an approximate indication of physiological maturity together with a rapid decline in grain moisture occurring at this time.

At ~12% moisture, the barley is ready for harvest. The current receival standards generally require delivered grain to have no more than 12.5% moisture. Storage of grain with higher moisture content is undesirable. [3]

1 N Poole (2005) Cereal growth stages guide. GRDC Publications, https://www.researchgate.net/file.PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798

2 GIWA Grain Standards in Western Australia http://www.giwa.org.au/standards

3 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

4.2 Germination and emergence

4.2.1 Germination

Germination begins when the seed absorbs water and ends with the appearance of the radicle. Germination has three phases:

- Phase 1: water absorption (imbibition)
- Phase 2: activation
- Phase 3: visible germination

Phase 1: Water absorption (GS01)

Phase 1 starts when the seed begins to absorb moisture. Generally, a barley seed needs to reach a moisture content of around 35–45% of its dry weight to begin germination. Water vapour can begin the germination process as rapidly as liquid can.

Barley seeds begin to germinate at a relative humidity of 97.7%. Soil so dry that roots cannot extract water still has a relative humidity of 99%, much higher than that of a dry seed. So even in dry conditions, there can be enough moisture for the seed to initiate germination, albeit at a slower pace than in damp conditions.

Phase 2: Activation (GS03)

Once the embryo has swollen, it produces hormones that stimulate enzyme activity. The enzymes break down starch and protein stored in the seed to sugars and amino acids, providing energy to the growing embryo. If the seed dries out before the embryo starts to grow, it remains viable.

Phase 2 continues until the rupture of the seed coat, the first visible sign of germination.

Phase 3: Visible germination (GS05–GS07)

In Phase 3 the embryo starts to grow visibly. The radicle emerges, followed soon after by primary roots and the coleoptile. The enzymes produced in Phase 2 mobilise sugars and amino acids stored in the seed and enable their transfer to the growing embryo. [4]

4.2.2 Emergence (GS07)

As the first primary roots appear, the coleoptile bursts through the seed coat and begins pushing towards the surface. Emergence is when the coleoptile of the first leaf becomes visible above the soil surface.

Coleoptile formation

The coleoptile is well developed in the embryo, forming a thimble-shaped structure covering the seedling leaf and the shoot. Once the coleoptile emerges from the seed, it increases in length until it breaks through the soil surface.

The fully elongated coleoptile is a tubular structure ranging from 50 to 80 mm in length and about 2 mm in diameter. It is white, except for two strands of tissue that contain chlorophyll. The end of the coleoptile is bullet shaped and is closed except for a small pore, 0.25 mm long, a short distance behind the tip.

When the coleoptile senses light, it stops growing and the first true leaf pushes through the pore at the tip. Up to this point, the plant is living on reserves within the seed. [5]

4 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

5 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

4.3 Factors affecting germination and emergence

4.3.1 Dormancy

In a barley seed, germination begins after a very short period of dormancy. Some level of seed dormancy is necessary to help prevent ripe grain from germinating in the head before harvest. However, excessive dormancy can be a problem in malting barley, forcing maltsters to store the grain for an extended period after harvest before it can be successfully malted. Australian varieties generally have low dormancy, some such as Hamelin and Flagship being particularly low.

At least two genes influence the level of dormancy in Australian barley. One gene is expressed in the embryo of the seed and needs to be present for any level of seed dormancy to develop. This gene makes the seed sensitive to the plant hormone abscisic acid, which prevents germination at crop maturity. The second gene is expressed in the seed coat and, in combination with the embryo gene, produces a more robust and stable dormancy. [6]

4.3.2 Moisture

Soil moisture influences the speed of germination. Germination is rapid if the soil is moist. When the soil dries to near the permanent wilting point, the speed of germination slows. When the soil reaches permanent wilting point, germination will take 10 days at 7°C, instead of five days at 7°C when there is adequate moisture.

The germination process in a seed may stop and start in response to available moisture. Seeds that have taken up water and entered Phase 2, but not reached Phase 3, remain viable if the soil dries out. When the next fall of rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2.

This ability to start and stop the germination process in response to conditions before the roots and coleoptile have emerged is an important consideration when dry-sowing. If the seedbed dries out before the coleoptile has emerged, the crop needs to be monitored to determine whether it will emerge, so that the critical decision to re-sow can be made.

Soil structure also affects emergence. Sowing into hard-setting or crusting soils that dry out after sowing may result in poor emergence. Hard soil makes it difficult for the coleoptile to push through to the surface, particularly in varieties with short coleoptiles. In some crusting soils, gypsum can improve soil structure and assist seedling emergence.

Stubble reduces the impact of raindrops on the soil surface and helps to prevent soil crusts from forming. Stubble retention also encourages biological activity and increases the amount of organic matter, which improves the stability of the soil by binding the soil particles together. [7]

4.4 Effect of temperature, photoperiod and climate on plant growth and physiology

4.4.1 Temperature

Germination

Germination is dependent on temperature. The ideal temperature for barley germination is 12–25°C, but germination will occur between 4°C and 37°C.

6 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

7 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

The speed of germination is driven by accumulated temperature, or degree-days. Degree-days are the sum of the average daily maximum and minimum temperatures over consecutive days compared with a base temperature. For barley, that is 0°C during vegetative growth and 3°C in the reproductive phase.

Barley requires 35 degree-days for visible germination to occur (Table 22). For example, at an average temperature of 7°C, it takes five days for visible germination to occur; at 10°C, it takes 3.5 days (Table 33).

Table 2: *Number of degree-days required for germination and emergence*

	No. of degree-days required
Root just visible	27
Coleoptile visible	35
Emergence (40 mm)	130
Each leaf	100

Source: UNE

Table 3: *Examples of how different temperatures affect germination*

Temperature	No. of days to germination
3.5°C	10
5°C	7
7°C	5
10°C	3.5

Source: UNE

Emergence

Extension of the coleoptile is directly related to soil temperature. Soils that are too cold or too hot shorten the coleoptile length. Research shows coleoptiles are longest when soil temperatures are 10–15°C. This results in variation in emergence and establishment times for different sowing dates and for different regions.

Establishment

High temperatures during establishment cause seedling mortality, reducing the number of plants that establish. In hot environments, the maximum temperature in the top few cm of soil can be 10–15°C higher than the maximum air temperature, especially with a dry, bare soil surface and high radiation intensity.

In these conditions, soil temperature can reach 40–45°C, seriously affecting seedling emergence. Brief exposure to extreme soil temperatures can also restrict root growth and tiller initiation.

Table 44 shows the average number of plants that establish with increasing soil temperatures, with seed at 100 kg/ha planted at a depth of 30–40 mm and soil temperature measured in the field at a depth of 50 mm.

Table 4: *Number of plants established at various soil temperatures.*

Mean max soil (°C)	No. of plants established per m^2
20.2°C	315
33.2°C	256
42.2°C	89

The difference between 20.2°C and 33.2°C is statistically significant. [8]

4.4.2 Oxygen

Oxygen is essential to the germination process. Seeds absorb oxygen rapidly during germination, and without enough oxygen, they die. Germination is slowed when the soil oxygen concentration is <20%. During germination, water softens the seed coat to make it permeable to oxygen; dry seeds absorb almost no oxygen.

Seeds planted in waterlogged soils cannot germinate because of a lack of oxygen. It is commonly thought that, in very wet conditions, seeds burst; in fact, they run out of oxygen and die. [9]

Coleoptile length

Coleoptile length is an important characteristic as it contributes to the maximum depth that a cultivar can be sown. Cultivars with a short coleoptile may fail to emerge in situations where the first internode cannot elongate enough to bring the crown close to the soil surface and allow the first true leaf to emerge.

Cultivars with a short coleoptile impact on the capacity of growers to chase moisture and sow seed at depths greater than 50 mm. The suggested sowing depth for barley in WA is 20–30 mm.

An improvement in the tolerance to deep seeding is likely to become an important adaptive trait for barley in Australia, as climate change is expected to increase the variability of the seasonal break, moisture availability during May and June, and decrease total in-season rainfall.

Research in WA has shown that coleoptile length of cultivars can range from 38 mm (Morell) to 93 mm (Doolup). Most of the 44 spring barley cultivars in the study had a coleoptile length between 60 and 80 mm. However, five cultivars (Buloke^⊕, Dash, Harrington, Morrell and Tallon) had a coleoptile length shorter than 60 mm. Seven cultivars (CM72, Doolup, Finniss, Fleet^⊕, Hannan, Haruna Nijo and Macumba had a coleoptile length longer than 80 mm.

The development of barley cultivars with a coleoptile length above 100 mm or a capacity to successfully emerge when sown below 100 mm could be useful and is a challenge for Australian barley breeders. Only two of the 44 cultivars evaluated in the study had a coleoptile length over 90 mm and none were over 100 mm.

Coleoptiles longer than 100 mm would be useful in assisting growers to sow closer to the optimum sowing time in situations where moisture is present at depth but not at the surface. Long coleoptiles would also be beneficial for growers in their tactical management at seeding including stubble management, furrow sowing and the use of seed fungicides and herbicides incorporated by seeding.

Genetic variation exists and markers have been identified that could be exploited to develop germplasm that could give more robust options for growers as they adopt management systems to deal with seasonal variability and the drying seasons of WA. [10]

4.4.3 Nutrition

Adequate nutrition is essential for good plant growth and development, yield and grain quality. Nutritional requirements vary depending on potential yield and soil-fertility status. A soil test should be carried out before sowing to measure soil nutrients and calculate fertiliser requirements.

8 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

9 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

10 B Paynter and G Clarke (2010) Coleoptile length of barley (*Hordeum vulgare L.*) cultivars. Genetic Resources and Crop Evolution. 57:395–403, https://www.researchgate.net/publication/226534038_Coleoptile_length_of_barley_Hordeum_vulgare_L_cultivars

Historically, rates of fertiliser application to barley crops have been low. Barley was perceived to perform well on poor soils and in low-fertility situations. This is not true. In fertile soils, barley will yield comparably to wheat without necessarily producing a protein level above that acceptable for malting specifications. [11]

Nitrogen

Nitrogen (N) is essential to plant growth and is commonly applied at moderate to high levels before or at sowing. Urea-ammonium nitrate or urea are commonly used to apply N at high rates. Different forms of fertiliser N need specific management.

Nitrogen can be leached from light soil if sowing is delayed by heavy rains or continuous wet weather. Excessive N fertiliser applied close to the seed can lead to toxicity problems. Under good moisture conditions, seed can tolerate a maximum of ~25 kg N/ha without seedling mortality. This amount is based on an 18-cm row spacing and fertiliser banded with the seed. Deep banding of N, which requires seed and fertiliser to be separated by >25 mm, and pre-drilling of urea at sowing are two methods that will prevent seedlings from overdosing on fertiliser.

Markets for malting barley demand moderate protein levels, and feed barley markets do not pay a premium for protein. Therefore, it is good practice to apply N fertilisers for vegetative growth early to give a higher yield potential, rather than having reserves of N at grainfilling that the plant will put into grain protein.

There is no reason to be wary of high-fertility paddocks or the use of N fertiliser to increase the yield potential of barley. After moderate additions of N, the protein percentage can remain relatively constant, whereas the yield can increase dramatically. High N availability or the use of high levels of N fertiliser can lead to an increase in grain protein but the major determinant of this is seasonal conditions during grainfill.

Nitrogen rates will vary depending on whether malt specifications are being targeted, the crop is being grazed, or the yield of a feed barley crop maximised. [12]

Phosphorus

Unlike N, phosphorus (P) is relatively immobile in the soil; therefore, it needs to be placed near the seed.

P is essential to seed germination, early root development and for increasing seedling vigour and establishment. Large amounts are taken up during early growth. Phosphorus deficiency at this early stage of growth significantly reduces yield potential. WA soils were very low in P, however with large amounts of P applied since clearing many soils now have adequate P levels for wheat and barley. Soil testing is critical to assess soil P levels, however it is recommended to use some starter P with all cereal crops as not all soil P may be available to the plant.

One method of estimating P requirement is to allow 4 kg P/t of target yield. For example, a barley crop of 3 t/ha requires 12 kg P/ha. Delays in the uptake of P to critical levels can delay maturity, which in turn can increase grain screenings. [13]

DAFWA research has shown that barley has a similar response to P as wheat.

MORE INFORMATION

R Malik and B Paynter (2015) Nitrogen rates and timing for new malting barley varieties. Agribusiness Crop Update.

11 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

12 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

13 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

Nutrition and fertiliser

With the more frequent use of opportunity cropping, improved farming techniques, and higher yielding varieties, grain growers need to continually review nutrient management programs to ensure the sustainability of grain production.

Common nutrient deficiencies include nitrogen (N), phosphorus (P), potassium (K) and zinc (Zn). Sulfur (S), copper (Cu), manganese (Mn) and molybdenum (Mo) may also be lacking in some soil types and growing areas. [1]

Historically, rates of fertiliser application to barley crops have been low. Barley was perceived to perform well on poor soils and in low-fertility situations. This is not the case; in fertile soils, barley yields are often 20% higher than those of wheat. [2]

Typically barley yields should be 250–500 kg/ha above wheat. Some barley growers in WA are regularly achieving yields 750–1000 kg/ha better than wheat.

Management of N availability is vital to achieving optimal yields and quality in barley crops. Unlike wheat, which attracts premiums for high protein, malting barley protein content needs to be between 9.5–12.5% to attract a premium. A protein target of 10% will also maximise a barley crop's yield potential. [3]

To help grain growers with nutrition knowledge, the GRDC set up the More Profit from Crop Nutrition Initiative. The primary outcome will be delivering to grain growers the knowledge and skills necessary to enable them to determine whether their current NPK application practices are efficient and meet best management practice. [4]

MORE INFORMATION

- GRDC (2014) Crop nutrition news.
- GRDC (2013) Better fertiliser decisions for crop nutrition. Fact sheet.
- GRDC (2012) More profit from nutrition. Ground Cover Issue 97 Supplement.
- GRDC (2007) Winter cereal nutrition: the Ute Guide
- DAFWA Fertiliser calculator
- W Pluske, et al. (2014) Best practice nutrient management: beyond the rhetoric.
- GRDC (2013) Managing Soil Organic Matter: A Practical Guide.
- Soil Quality: Organic Carbon Storage—Western Australia. Fact sheet.

5.1 Organic matter

Organic matter is primarily made up of carbon (45%) with the remaining mass consisting of water and other nutrients. [5] It has a fundamental role in soils and helps to ameliorate or buffer the harmful effects of plant pathogens and chemical toxicities. It enhances surface and deeper soil structure, with positive effects for infiltration and exchange of water and gases, and for keeping the soil in place (i.e. reducing erosion). It improves soil water-holding capacity and, through its high cation-exchange capacity (CEC), prevents the leaching of essential cations such as calcium (Ca), magnesium (Mg), K and sodium (Na). Most importantly, it is a major repository for the cycling of nutrients and their delivery to crops and pastures.

5.2 Declining soil fertility

The natural fertility of cropped agricultural soils can decline over time. As a result, management programs need regular review to ensure the long-term sustainability of high-quality grain production. Legume pasture phases, pulse rotations and regular liming applications all play an important role in maintaining the chemical, biological and physical fertility of soils (Photo 1).

Paddock records, including yield and protein levels, fertiliser test strips, crop monitoring, and soil and plant tissue tests all assist in the formulation of an efficient cropping program.

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

2 N Fettell, P Bowden, T McNee, N Border (2010) Barley Growth & development, PROCROP. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

3 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

4 M Blumenthal, I Fillery (2012) More profit from crop nutrition. GRDC Ground Cover Supplement, 16 February 2012, http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-issue-97-MarApr-2012-Supplement-More-profit-from-nutrition/More-profit-from-crop-nutrition

5 DAFWA (2016) Soil organic matter. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/soil-carbon/soil-organic-matter-frequently-asked-questions-faqs

Although crop rotations with pulses and legume pastures play an important role in maintaining and improving soil fertility, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed.

The yield potential of a crop will be limited by any nutrient the soil cannot adequately supply. Poor crop response to one nutrient is often linked to a deficiency in another nutrient. Sometimes, poor crop response can also be linked to acidity, sodicity or salinity, pathogens, or a lack of beneficial soil microorganisms. [6]

Photo 1: *The natural fertility of cropped agricultural soils can decline over time.*

5.3 Balanced nutrition

To obtain the maximum benefit from investment, fertiliser programs must provide a balance of required nutrients. There is little point in applying N if a P or Zn deficiency is limiting yield. To make better crop nutrition decisions, growers need to consider the use of paddock records, soil and tissue tests as well as fertiliser test strips. This helps to build an understanding of which nutrients the crop removes at a range of yield and protein levels.

The use of paddock grain protein to detect N deficiency is well established for wheat and barley. Grain protein lower than 10% is likely to indicate loss of yield due to inadequate N supply. [7]

Monitoring of crop growth during the season can assist in identifying factors such as water stress, P or Zn deficiency, disease or other management practices responsible for reducing yield. [8]

5.3.1 Paddock records

Paddock records help to:

- establish realistic target grain yield and protein levels prior to planting

6 DAF Qld (2010) Nutrition management. Overview. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

7 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

8 DAF Qld (2010) Nutrition management. Overview. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

- modify target yield and protein levels based on previous crop performance (yield and protein), planting soil moisture, planting time, fallow conditions, expected in-crop seasonal conditions and grain quality requirements
- determine appropriate fertiliser type, rate and application method
- compare expected with actual performance per paddock and modify fertiliser strategies to optimise future yield and protein levels

The longer paddock records are kept, the more valuable they become in assessing future requirements. [9]

5.4 Understanding soil pH

Soil acidity is a major constraint to farming in WA. Extensive surveys of soil pH profiles across the south-west show more than 70% of surface soils and almost half of subsurface soils are below appropriate pH levels.

Soil acidity is an economic and natural resource threat. Production loss and sustainability are of major concern to growers, with more than 14.25 million ha of wheatbelt soils currently estimated to be acidic or at risk of becoming acidic to the point of restricting production. The estimate of production loss for the wheatbelt due to acidity is $498 million, or about 9% of the annual crop. [10]

Getting pH right is the most important factor affecting barley nutrition and production. All the other nutrition falls into line once the optimum pH is achieved.

A soil pH in calcium chloride ($CaCl_2$) of 5.2–8.0 provides optimum conditions for most agricultural plants. All plants are affected by extremes of pH, but there is wide variation in their tolerance of acidity and alkalinity. Some plants grow well over a wide pH range, whereas others are very sensitive to small variations in acidity or alkalinity. Barley is generally sensitive to soil pH <5.0.

Microbial activity in the soil is also affected by soil pH, with most activity occurring in soils of pH 5.0–7.0. Where extremities of acidity or alkalinity occur, various species of earthworms and nitrifying bacteria disappear.

Soil pH affects the availability of nutrients, and affects how the nutrients react with each other.

At low pH, beneficial elements such as Mo, P, Mg, S, K, Ca, and N become less available and others may become toxic (Figure 1). Maintain soil pH ($CaCl_2$) at 5.5–6.5 to achieve maximum P availability for cereals. [11]

9 DAF Qld (2010) Nutrition management. Overview. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

10 DAFWA (2016) Soil acidity in Western Australia. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/soil-acidity/soil-acidity-western-australia

11 B Lake (2000) Understanding soil pH. Acid Soil Management Series. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf

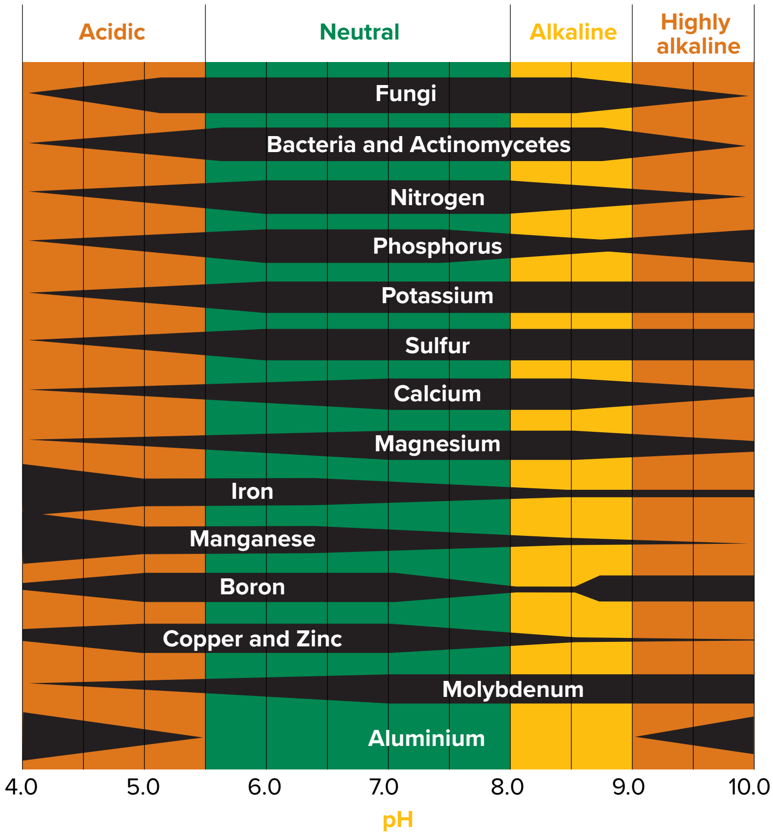

Figure 1: *Availability of nutrients and other elements varies with soil pH.*

Source: NSW DPI

MORE INFORMATION

DAFWA (2016) Soil acidity in Western Australia.

NSW Agriculture (2000) Understanding soil pH.

GRDC (2015) pH-mapping and variable rate lime—50,000 plus hectares of experience. GRDC Update Paper.

5.5 Hierarchy of crop fertility needs

The hierarchy of crop fertility needs says there must be sufficient plant-available N to obtain a response to P, and there must be sufficient P for S and/or K responses to occur. [12]

Additive effects of N and P appear to account for most of the aboveground growth and yield response. [13]

Liebig's law of the minimum is a principle developed in agricultural science by Carl Sprengel (1828) and later popularised by Justus von Liebig. It states that growth is controlled not by the total amount of resources available, but by the scarcest resource (i.e. limiting factor) (Figure 2). [14]

12 D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers, 7 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs

13 D Lester, M Bell (2013) Nutritional interactions of N, P, K and S on the Darling Downs. GRDC Update Papers 7 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs

14 Liebig's law of the minimum. Wikipedia, http://en.wikipedia.org/wiki/Liebig's_law_of_the_minimum

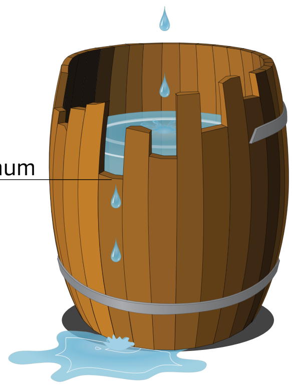

Figure 2: *Liebig's law of the minimum.*

5.6 Crop removal rates

Ultimately, nutrients removed from paddocks will need to be replaced to sustain production. Table 1 shows amounts of nutrients removed by barley and wheat. Growers need to adopt a strategy of programmed nutrient replacement based on yields and protein taken off paddocks.

Table 1: *Average amounts of nutrients (kg/ha) removed per tonne of grain and stubble for barley and wheat*

	N	P	K	S	Mg	Ca	Cu	Zn	Mn
Wheat –Grain	21	3	4	2	1	0.4	0.003	0.02	0.02
Wheat – Straw	4–6	0.5–1	9–10	1–2					
Barley –Grain	21	3	4	2	1	0.4	0.003	0.02	0.03
Barley – Straw	4–6	0.5–1	10–11	1–2					

Source: CSBP

To attain optimum yields, an adequate supply of each nutrient is necessary. However, only a small proportion of the total amount of an element in the soil may be available for plant uptake at any one time. For nutrients to be readily available to plants, they must be present in the soil solution (the soil water), or easily exchanged from the surface of clay and organic matter particles in the root-zone, and be supplied when and where the plant needs it.

Temperature and soil moisture content affect the availability of nutrients to plants. The availability of nutrients also depends on soil pH, degree of exploration of root systems, and various soil chemical reactions, which vary from soil to soil. Fertiliser may be applied in the top 5–10 cm, but unless the soil remains moist, the plant will not be able to access it. Movement of nutrients within the soil profile in low-rainfall areas is generally low, except in very sandy soils, and some nutrients, such as P and Zn, are relatively immobile in the soil.

Lack of movement of nutrients, combined with current farming methods (e.g. no-till), is resulting in stratification of these nutrients, with concentrations building up in the surface of the soil where they are not always available to plants. Deep sowing is done into moisture that is below the layer where nutrients have been placed or are stratified, and this has implications for management and fertiliser practices. [15]

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

5.7 Soil testing

Soil tests estimate the amount of each nutrient available to the plant. Information obtainable from a soil test includes current nutrient status, acidity or alkalinity (pH), soil salinity (electrical conductivity, EC) and sodicity (exchangeable sodium percentage).

Soil test information should not be used alone to determine nutrient requirements. It should be used in conjunction with tissue tests (especially for trace elements) along with test-strip and previous crop performance to determine nutrients removed by that crop, and previous soil test records, to obtain as much information as possible about the nutrient status of a particular paddock.

Care must be taken when interpreting soil test results. Nutrients can become stranded in the dry surface layer of the soil after many years of no-till or reduced tillage, or deep nutrient reserves may be unavailable because of other soil factors such as EC levels, sodicity or acidity. [16]

Principal reasons for soil testing for nutrition include:

- monitoring soil fertility levels
- estimating which nutrients are likely to limit yield
- measuring properties such as pH, sodicity and salinity, which affect the crop demand as well as the ability to access nutrients
- zoning paddocks for variable application rates
- as a diagnostic tool, to identify reasons for poor plant performance [17]

Soil test results support decisions about fertiliser rate, timing and placement. However, to determine micronutrient status, plant tissue testing is usually more reliable.

MORE INFORMATION

GRDC (2014) Soil testing for crop nutrition (Western Region) Fact sheet.

CSIRO Publishing (2016) Interpreting Soil Test Results What Do All the Numbers Mean

GRDC (2016) Enhancing the sustainability of the Western Australia cropping system by using soil and plant testing combined with nutrient balance calculations. GRDC Research Update.

5.7.1 Critical values and ranges

A soil-test critical value is the soil-test value required to achieve 90% of crop yield potential. The critical range around the critical value indicates the reliability of that single value. The narrower the range the more reliable the data.

The critical value indicates whether nutrient supply is likely to result in a crop yield response. If the soil test value is less than the lower limit of the range, the site is highly likely to respond to an application of the nutrient.

For values within the critical range, there is less certainty about whether a response will occur. If a response does occur, it will likely be small.

The values used to determine the soil test–crop response relationship have been derived from fertiliser rate trials, in which various fertiliser rates are applied and the crop yield response is measured. With many of these experiments, soil test values and crop responses can be graphed. [18]

PODCAST

GRDC (2014) Soil Testing. Driving Agronomy Podcasts.

5.7.2 Fertiliser test strips

Test strips within the paddock allows the fertiliser program to fine-tuned. To gain the maximum benefit:

- Run them over a number of years; results from any single year can be misleading
- Obtain accurate strip yield weights
- Protein-test a sample of grain from each strip
- Harvest strips before your main harvest, because the difference between the strips is more important than the moisture content

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16 DAF Qld (2010) Nutrition management—Overview. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

17 GRDC (2014) Soil testing of crop nutrition. Western Region. Crop Nutrition Fact Sheet, GRDC, January 2014, https://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-West

18 GRDC (2014) Soil testing of crop nutrition. Western Region. Crop Nutrition Fact Sheet, GRDC, January 2014, https://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-West

When setting up a test-strip area:

- Ensure the stripscan be accurately located—a GPS reading would be valuable
- Repeat each fertiliser treatment two or three times
- Change only one product rate at a time
- Separate each strip of fertiliser by a control or nil-fertiliser strip
- Ensure that tests are done over a part of the paddock with a uniform soil type
- Keep clear of shade lines, trees, fences, headlands and any known anomalies in the field
- Ensure the test strip area is ~100 m long, with each strip 1–2 header widths [19]

MORE INFORMATION

A number of local Grower Groups conduct nutrition trials.

GRDC (2016) Test strips reduce nitrogen risk. GRDC Radio (Western region) 123:

GRDC (2013) Better fertiliser decisions for crop nutrition. Fact sheet.

CSIRO Publishing, Australian Soil Fertility Manual.

5.7.3 Sampling guidelines

Choose the same soil test package each year (including methods); otherwise, comparisons between years will be invalid. For example, do not use Colwell-P in one year, then DGT-P the next; the two tests measure different forms of available P in the soil.

If a standard approach is not applied to sampling, a comparison of the data between different tests will not be reliable. Aim for data that represents the whole paddock, and mix the sample thoroughly.

For monitoring, sampling should cover roughly the same area each time to ensure meaningful comparisons between years. A handheld GPS or smartphone, will serve this purpose. It can be useful to follow up on a soil test site with an in crop tissue test to evaluate nutrient uptake.

Soil-testing laboratories should be able to provide information on appropriate soil sampling and sample-handling protocols for specific industries and crop types. [20]

5.7.4 Soil testing for nitrogen

The approximate amount of N available in the soil can be determined by soil testing. Soil tests can be taken at various places in each paddock down to a depth of 60 cm or to a known rooting depth. [21] However, deep soil testing for N is not commonly practised in WA as it can be unreliable on the sandy and loamy soil types.

Historical grain yield and protein levels from the paddock can be used to assist N-requirement decision making. [22]

Environmental conditions, including temperature, time and rainfall events can affect starting soil N. It is important to test later in summer and make adjustments to factor in mineralisation amounts as well as denitrification and leaching events if they occur.

Calculating N fertiliser application

If N fertiliser is required, the equation below can be used to obtain the quantity of fertiliser required:

Fertiliser product required (kg/ha) = rate of N required (kg/ha) × 100/% N in fertiliser product [23]

For example, if 40 kg N/ha is required, this rate of N can be supplied by applying 87 kg/ha of urea (46% N).

19 DAF Qld (2010) Nutrition management—Overview. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

20 GRDC (2013) Better fertiliser decisions for crop nutrition. Crop Nutrition Fact Sheet, GRDC, 4 November 2013, http://www.grdc.com.au/GRDC-FS-BFDCN

21 NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

22 DAF Qld (2010) Nutrition management—Overview. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

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

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GRDC (2014) Soil testing for crop nutrition (Western Region). Fact sheet.

CSIRO (2002) Research paper: A simple phosphorus buffering index for Australian soils.

GRDC (2010) Plant tissue testing-uncovering hidden hunger. Driving Agronomy Podcast.

GRDC (2011) Current nutrition issues in the cropping zone of Southern Australia. GRDC Update Paper.

5.7.5 Soil testing for phosphorus

While a number of different P tests are used in Australia, the vast majority of calibration data for soil phosphorus in cropping is for Colwell P. Recent research has led to the introduction of the DGT-P test for cropping. Colwell P is not used in isolation in WA, but with PBI. DGT-P was developed for more alkaline soils such as those found in SA, so is not preferable in WA's more acidic soils

It is crucial that growers use the same test across paddocks and across years. [24]

5.8 Plant and/or tissue testing for nutrition levels

Tissue testing is the best way to diagnose nutrient deficiencies accurately when a crop is growing, whether it is macronutrients, or micronutrients such as Zn and Cu.

Successful use of plant-tissue analysis depends on sampling the correct plant part, at the appropriate growth stage. Sampling of whole tops is easily the most common sampling method in WA. The critical concentration of most nutrients changes with age. [25]

For these reasons, critical tissue concentrations should be associated specifically with defined stages of plant growth or plant part rather than growth periods (i.e. days from sowing). Growers are advised to follow laboratory guides or instructions for sample collection.

Plant nutrient status varies according to plant age, variety, levels of other nutrients, weather conditions, and stresses such as frost.

When applying fertiliser to treat a suspected deficiency, leave a strip untreated. Either a visual response (a yield difference <20% is difficult for the human eye to detect) or a harvester yield map will confirm whether the micronutrient was limiting. [26]

5.9 In-crop nutritional needs

5.10 Nitrogen

Among the mineral nutrients, nitrogen (N) is required in the largest amounts and is the most common nutrient deficiency in non-legume plants. Increased vegetative growth (and tillering in cereals) is often seen with N application and protein content is also enhanced. Nitrogen is mobile in both the soil and the plant. Most of the N in soils (98% or more) occurs in organic forms. This must be mineralised to the inorganic ammonium and nitrate forms before plant roots can utilise this N.

Nitrogen is required for protein formation and determines yield and grain quality.

Nitrogen deficiency can occur on most WA soils but is most common in the following situations:

- In cold, wet conditions that slow nitrogen mineralisation and uptake of nitrogen
- Soils with very low organic matter
- High rainfall on sandy soils can result in nitrogen leaching [27]

Predicting N supply to crops is complex. Nitrogen demand by the crop is related to actual yield, which is determined by seasonal conditions including the amount and timing of growing season rainfall.

24 GRDC (2014) Crop Nutrition News. GRDC, https://grdc.com.au/Media-Centre/GRDC-E-Newsletters/Crop-Nutrition-News

25 James Easton, CSBP. Pers comm.

26 GRDC (2013) Micronutrients. Northern, Southern and Western Regions. Crop Nutrition Fact Sheet, GRDC, November 2013, http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients

27 DAFWA (2015) Diagnosing nitrogen deficiency in barley, Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-barley

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L Barton et al. (2015) Increasing soil organic carbon increases soil nitrogen: Implications for crop production on sandy soils.

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GRDC (2015) Legume effects on soil N dynamics—comparisons of crop response to legume and fertiliser N. GRDC Update Paper.

GRDC (2014) Nitrogen management—how much is enough and how much is too much? GRDC Update Paper.

GRDC (2011) Management effects on barley varieties—nitrogen management and time of sowing. GRDC Update Paper.

BCG: Barley and wheat disease management using foliar and fertiliser fungicides

BCG: Late nitrogen application to increase grain protein in barley

BCG: Management effects on barley varieties—row spacing, nitrogen and weed competition

The pattern of crop demand for N during the growing season should be considered. The highest demand is when the crop is growing most rapidly. [28]

In WA, fertiliser recommendations for N are generally based around a budgeting approach, using a series of relatively simple, well-developed equations that estimate plant demand for N and the soil's capacity to supply N.

These equations attempt to predict the soil processes of mineralisation, immobilisation, leaching, volatilisation, denitrification and plant uptake. They are built into decision support tools such as Yield Prophet® and Select Your Nitrogen (SYN). Yield Prophet® requires a detailed characterisation of the physical and chemical properties of the soil profile explored by the roots. [29]

Plant tissue testing is also a very useful in season tool to refine initial recommendations. [30]

5.10.1 Time of application

Most responses to nitrogenous fertiliser in WA are the result of an increased number of ears or grains.

The response is largely caused by increased tillering, which is determined early in the life of a barley plant. The number of grains per ear is also determined early. Therefore, a good supply of N is needed early in crop growth. Early application is preferred in the production of malting barley because it is more likely to increase yield without raising grain protein levels.

The other consideration is that in sandy soils in higher rainfall areas, the application should be split or delayed 3–4 weeks. This allows the crop to establish a reasonable root system and avoid large leaching losses.

The best time of application in any one season can vary depending largely on the incidence of leaching rains in relation to time of application. Profitable responses can often be obtained up to 10 weeks after sowing. Late applications are more likely to result in increased grain protein. In high yielding sites this can be beneficial to stay in the malt window and can result in lower yielding environments it results in excess protein.

Generally, the later the application, the lower the response and the greater the risk of not getting a payable response. Responses to later applications are generally a result of better survival of tillers and to increased photosynthetic area. [31]

FAQ

5.10.2 Nitrogen supply and grain protein content

Nitrogen is a primary constituent of protein; therefore, adequate soil N supply is essential for producing cereal grain protein. Supply of N is shaped by a number of factors in the farming system (Figure 3) and the N cycle (Figure 4).

28 GRDC (2014) Soil testing for crop nutrition. Western Region. Crop Nutrition Fact Sheet, GRDC, January 2014. https://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-West

29 GRDC (2014) Soil testing for crop nutrition. Western Region. Crop Nutrition Fact Sheet, GRDC, January 2014, https://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-West

30 J. Easton, CSBP. Pers comm.

31 DAFWA (1995) The Barley Book. Department of Agriculture and Food, Western Australia, http://researchlibrary.agric.wa.gov.au/bulletins/44/

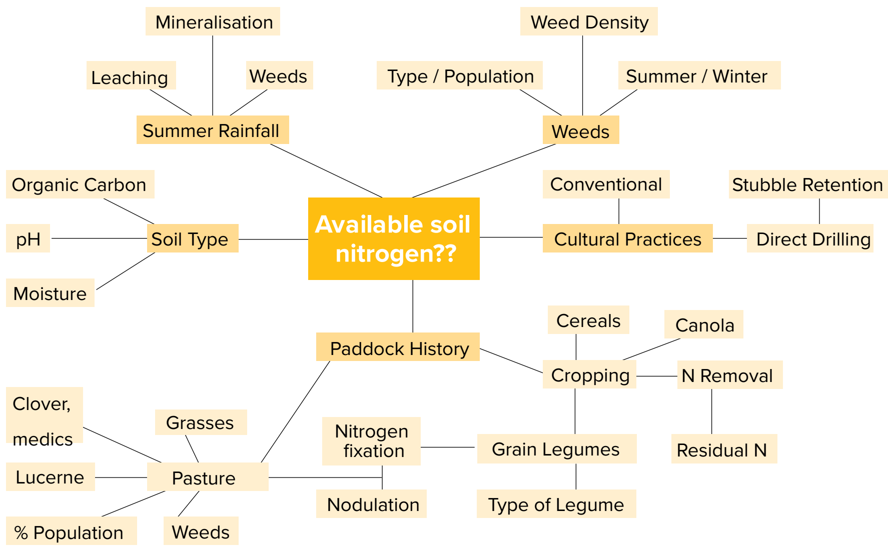

Figure 3: *Factors influencing available soil nitrogen.*

Source: Incitec Pivot Ltd

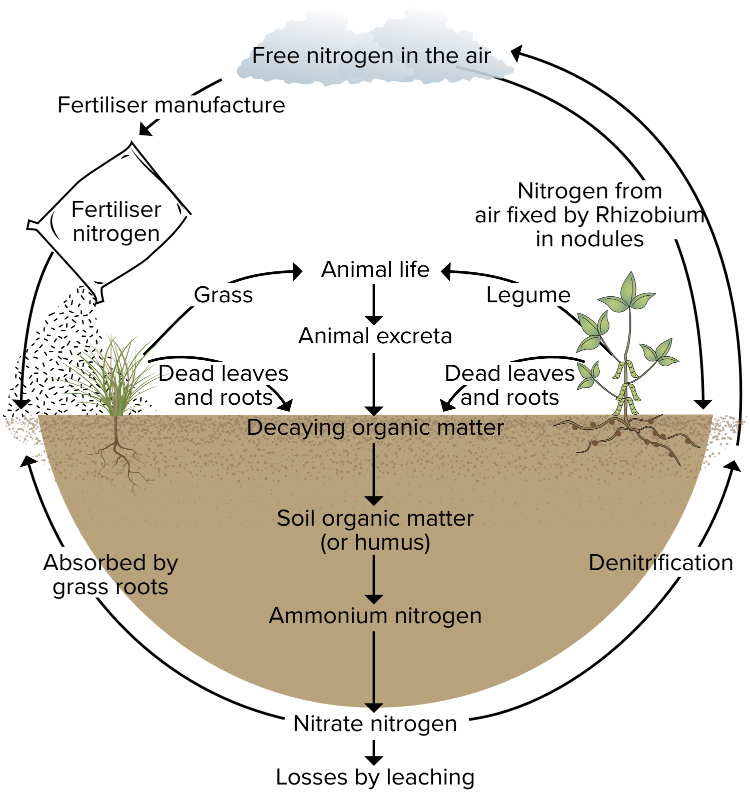

Figure 4: *The soil nitrogen cycle.*

Source: Agriculture Victoria

Besides its role in plant growth, the availability of soil N at grainfill, along with soil moisture, is the key determinant of grain protein. Crop rotation and management are key factors in determining the accumulation of soil N. The availability of N in the soil will be affected by many factors: soil organic matter, paddock history, soil type, moisture content, time of year, and tillage methods.

High yields are a drain on soil N. Conversely, low yields and summer rain which mineralise N can mobilise soil N for the next crop. Soil tests for N should be done as close as possible to sowing time. [32]

Grain protein content

Grain protein is modified by the grain yield of the crop—increasing grain yield has a diluting effect on grain protein, (i.e. yield and protein are inversely proportional) (Figure 5). This explains why in drier seasons or seasons of low grain yield, a larger proportion of the crop has a high protein content. In wetter years, high yields can be produced but may be at a lower protein level. A barley crop's N requirement can be extremely variable from one year to the next.

As the rate of N supply is increased, yield will generally increase to a maximum level, whereas protein may continue to increase with further N application. Drier or wetter than expected seasonal conditions can significantly change yield potential mid-season, which consequently changes N requirements to meet target protein contents. [33]

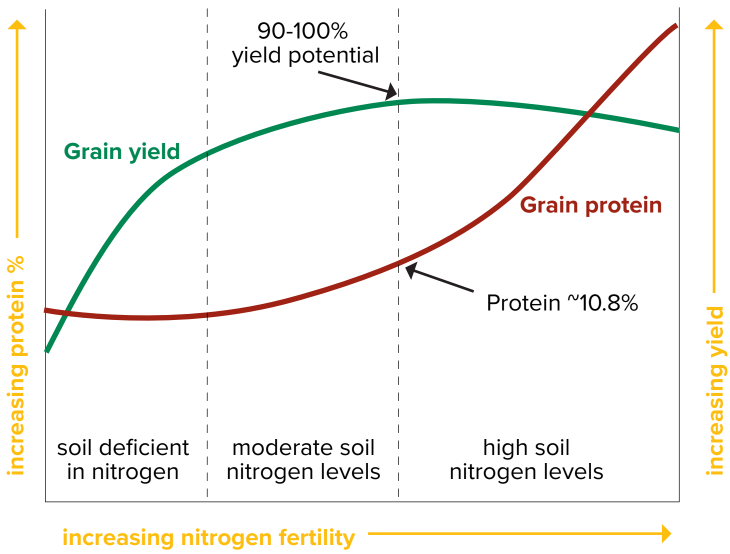

Figure 5: *Relationship between grain yield and protein.*

Source: Incitec Pivot Ltd

5.10.3 Plant-available (nitrate)-N in the root-zone

Nitrogen in the plant-available, mineral form is a major driver of crop production. Almost all of the N taken up by crops is in the form of nitrate. The other mineral form, ammonium, is present in most soils at low levels.

32 Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat

33 N Fettell, P Bowden, T McNee, N Border (2010) Barley Growth & development, PROCROP. Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

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GRDC (2015): Where does fertiliser nitrogen finish up? GRDC Update Paper.

PODCAST

GRDC (2015) Nitrogen Management. Driving Agronomy Podcast.

In some soils, subsoil constraints will limit the root-zone to <1 m. In other soils that are particularly well structured, the root-zones of long-season or particularly vigorous crops can be as deep as 1.8 m.

5.10.4 Nitrogen deficiency symptoms

Description:

- Plants are pale green with reduced bulk and tiller formation (Photo 2 and Photo 3)
- Symptoms first occur on the oldest leaf, which becomes paler than other leaves, with marked yellowing beginning at the tip and gradually merging into light green
- Other leaves begin to yellow and oldest leaves change from yellow to almost white
- Leaves may not die for some time
- Grain yield and protein levels are reduced

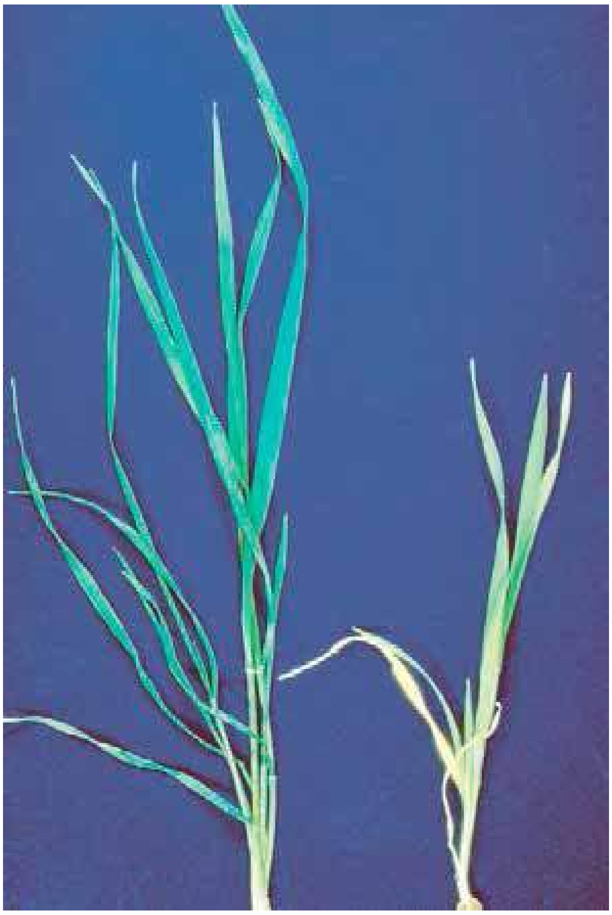

Photo 2: *Adequate (left) and inadequate (right) nitrogen nutrition.* [34]

Source: Mel Mason, Agriculture WA

34 GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

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L Barton et al. (2015) Where does the nitrogen go? Soil sources and sinks in Western Australia cropping soils.

GRDC (2014) Nitrogen volatilisation: Factors affecting how much N is lost and how much is left over time. GRDC Update Paper.

Soil Quality (2017) Soil nitrogen supply. Fact sheet.

Photo 3: *Inadequate nitrogen nutrition expressed as pale green plants with reduced bulk and tiller formation.*

Similar symptoms

Deficiencies of K and P show similar yellowing of the oldest leaves, but these leaves die quickly. Reduced grain yield and protein levels may occur for other reasons. [35]

5.10.5 Nitrogen-use efficiency

Efficient use of N is crucial to economic production of cereals. Over-application of N may increase susceptibility of the crop to disease and increase water use early in the growing season. This creates excessive early growth, causing crops to 'hay off'.

Split application

Site and N rate are the primary determinants of grain protein levels in barley; the impact of variety and split applications are secondary. However, splitting N applications offers growers the capacity to tailor N inputs to the crop growth and seasonal forecast. Nitrogen application generally decreases average grain weight in barley and this can result in increased screenings.

While the rate applied is significant, timing is still an important component of getting the rate right. Research shows that growers can split N applications and sow with a starter amount of N and then delay the second application out to stem elongation or beyond.

The advantage of this is a better assessment of the yield potential of each crop as its growth reflects seasonal challenges such as disease pressure, growing conditions and the ability to factor in seasonal forecasts for spring rainfall. It is critical to match yield potential with the level of N required to achieve that yield potential. [36]

Late applications

Applying N after tillering offers farmers advantages, such as better estimates of the overall rate required based on likely yield potential and it avoids excessive tiller numbers in varieties that tiller profusely in response to early applications of N. Logistically, later applications can also be made when another operation such as disease control is being done.

Nitrogen applied as late as flag leaf emergence does not increase screenings more than those made earlier in the season at tillering. The stem elongation stage

35 GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

36 A Hills and B Paynter (2008) Managing nitrogen inputs in malting barley. Agribusiness Crop Updates 2008, https://www.researchgate.net/publication/273135464_Managing_nitrogen_inputs_in_malting_barley

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[GRDC (2015) Phosphorus—are we going to hit the wall and how much P in 2015? GRDC Update Paper.]

[GRDC (2015) Subsoil manuring. GRDC Update Paper.]

[GRDC (2012) Crop nutrition—Western Region phosphorus management. Fact Sheet.]

[MDA Bolland and DG Allen (2003) Sorption of phosphorus by soils: how it is measured in Western Australia.]

[GRDC (2015) Phosphorus—are we going to hit the wall and how much P in 2015? GRDC Update Paper.]

[GRDC (2015) Subsoil manuring. GRDC Update Paper.]

of growth appears to be sensitive to N and may produce higher screenings than N applied earlier or later.

Maintaining a high grain yield is important in the southern region of WA as weather conditions at harvest can result in the downgrading of grain into feed segregations. [37]

As a rough rule of thumb plan to apply 10–20% more N to barley crops than to a wheat crop in a similar rotation because barley usually has a higher yield potential than wheat (400-800 kg/ha).

Agronomist's view

5.11 Phosphorus

Native soils in WA are among the most highly phosphorus (P) deficient in the world. Although N and K are required in larger amounts for plant growth, P deficiency was one of the major limitations to agriculture in WA for many years. Apart from the very sandy soils with little clay or organic matter, most WA soils retain P tightly. In the year of application, 80–95% of the P applied in fertilisers reacts with soil particles before it can be taken up by the plant roots. This process is known as adsorption.

Over time, as more and more P is added to the soil, the adsorbed P builds up and can return to the soil solution to be utilised by plants.

Phosphorus is an essential element for plant and animal growth and is important during cell division and growth (e.g. during development of roots, flowering and seed formation). Complex soil processes influence the availability of P applied to the soil, with many soils able to 'tie up' P, making it unavailable to plants. [38]

Nearly all soils in WA were P deficient but continual use of P fertiliser means that P responses are less common and most grain growers now fertilise to maintain soil P levels with the exception of Darling Range gravels where soil acidity and water repellence markedly reduce P uptake. Phosphorus deficiency is often transitory and compounded by dry soil with symptoms disappearing when the topsoil is re-wet following rainfall. [39]

Roots of all plant species can only take up water-soluble P from soil solution. Plant roots intercept P in moist soil as the roots grow through the soil, and P moves through the soil solution to the root by diffusion. [40]

5.11.1 Phosphorus deficiency

P deficiency symptons include (Photo 4 and Photo 5):

- Early growth and vigour are reduced, with spindly plants under severe deficiency
- All leaves are dull dark green
- Slight mottling is visible on oldest leaf and tip begins to yellow
- Yellow area moves down the leaf, with the base remaining dark green (no 'arrow', so not like K deficiency)
- Yellow areas die quite quickly, with the tip becoming orange to dark brown and shrivelling, with the remainder of the leaf turning yellow [41]

37 A Hills and B Paynter (2009) Time of nitrogen application effects on grain yield and quality of malting barley. 14th Australian Barley Technical Symposium, 13–16 September 2009. https://www.researchgate.net/publication/274067552_Time_of_nitrogen_application_effects_on_grain_yield_and_quality_of_malting_barley

38 Soil Quality (2017 Phosphorus–WA. Fact sheet, http://www.soilquality.org.au/factsheets/phosphorus

39 DAFWA (2015) Diagnosing phosphorus deficiency in barley, Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2538

40 MDA Bolland and DG Allen (2003) Sorption of phosphorus by soils: how it is measured in Western Australia, Department of Agriculture and Food, Western Australia, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1035&context=bulletins

41 GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

Photo 4: *Adequate (left) and inadequate (right) phosphorus nutrition.* [42]

Photos: Nigel Wilhelm, SARDI

Photo 5: *Phosphorus deficiency on the right-hand side of the image.*

Source: Nigel Wilhelm, SARDI

Similar symptoms

Nitrogen deficiency also has yellowing of the oldest leaves, but death of the yellow tissue occurs more rapidly in P deficiency than with N deficiency.

5.11.2 Crop demand for phosphorus

Crop demand for P can be considered in two distinct phases: during early development (from emergence to the end of tillering, but before stem elongation), and then during the growth and grain-filling period.

42 GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

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GRDC (2014) Soil testing for crop nutrition Western Region. Fact sheet.

Large increases in soil pH can improve the availability of soil phosphorus if the supply of other nutrients is adequate http://www.giwa.org.au/_literature_209549/Scanlan,_Craig_et_al_-_The_interaction_between_soil_pH_and_phosphorus_fertiliser_is_dynamic

During early development, the requirement for P is small (perhaps 1 kg/ha P), but the root system is small and inefficient, so the crop responds to a concentrated P source close to the seed and developing roots. Ensuring these young plants have adequate P is essential to determine grain number (i.e. yield potential) and to ensure vigorous seedling development. Hence, it is important to apply 'starter fertilisers' with the seed.

Subsequent P requirement is much larger, and largely mirrors the accumulation of crop biomass. As a rule, crops require ~5 kg P plant-accumulated to produce 1 t of grain yield, so a typical crop of 3 t/ha will take up ~15 kg/ha P. Only 1–2 kg will be taken up from the banded P fertiliser applied at planting (either in, below or beside the seeding row). The rest comes from the soil profile, with about half coming from the top 10–15 cm and the rest from the next 15–30 cm. These proportions will change with seasonal conditions; root activity in surface layers will be minimal in dry periods. Having plant-available P in the immediate subsoil (i.e. 10–30 cm preferably) becomes a critical factor for crop performance. [43]

5.11.3 Phosphorus availability

Many studies suggest that the timing and quantities of P release vary and that they are not well explained by the total amount of P or the carbon (C)P ratio in the residues.

The chemical composition of crop stubble plays an important role in the rate of nutrient release. The quality of crop stubble is usually assessed by considering its C:N:P ratio, because this ratio influences the proportion of P that follows pathways of immediate release or incorporation by microorganisms and subsequent release back to the soil.

This occurs because the microbial population requires a C source for energy, which is provided by the stubble, as well as certain amounts of nutrients such as N and P to continue to grow. How crop stubble affects soil P availability will therefore depend on the balance between direct release of P (and C and N) from the stubble and microbial uptake and release. The presence of different chemical P forms in the stubble is also likely to influence the proportion of P that undergoes direct release or microbial uptake and decomposition.

Research indicates that P release is strongly controlled by the size of the stubble pieces, and studies that use ground stubbles are likely to over-predict the rate at which P is released from stubble in the field. [44]

Where soil pH is below recommended levels, yield potential is reduced as is the availability of soil P. Both of these factors are major drivers of the profit achieved from P fertiliser. In WA trials, when yield was constrained by soil pH, treatments where 20–30 kg P/ha were applied did not achieve the same grain yield as treatments with soil pH at or above recommended levels with no or low P fertiliser applied. In this scenario, it seems logical to adjust fertiliser inputs to realistic yield potentials and shift investment to lime. [45]

5.11.4 Reduced tillage

Reduced tillage or no-tillage may accentuate the responsiveness of a soil to phosphate fertiliser. This is due to the stratificationof phosphate in the soil surface. Phosphorus is immobile in the soil—unlike nitrate-N, it does not move in soil water. Phosphate fertilisers are most effective when applied at planting in direct contact with, or just below, the seed. Table 5 shows the actual rate of fertiliser product required to apply various rates of P.

43 DAF Qld (2012) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition

44 S Noack, M McLaughlin, R Smernik, T McBeath, R Armstrong (2012) The value of phosphorus in crop stubble. GRDC Update Papers, 23 February 2012

45 W Pluske, C Scanlan, R Norton (2014) Best practice nutrient management: beyond the rhetoric, http://www.giwa.org.au/pdfs/2014/Presented_Papers/Pluske%20Wayne_Best%20practice%20nutrient%20management%20beyond%20the%20rhetoric_PAPER%20DR.pdf

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GRDC (2014) Soil acidity and phosphorus in western spotlight. GRDC Ground Cover 108.

GRDC (2014) Crop Nutrition: Region by Region. GRDC Ground Cover 108.

5.11.5 Phosphorus application

The traditional practice of banding P below or with the seed seeks to provide a rapid boost to root growth, promoting vigorous root systems, which can then set the plant up for good yields. In the presence of root diseases such as nematodes and rhizoctonia starter P is very critical as early root growth is reduced.

On soils that have the capacity to retain P, such as the ironstone gravel soils east of the Darling Range, it is best to drill fertiliser with the seed.

Spreading P by top dressing during the growing season is highly inefficient and should be avoided on cereal crops. Because crop requirements for P tend to be greatest during early growth, it is essential that the P management is implemented correctly at sowing. It is very difficult to correct mistakes later in the season. Foliar P is not yet considered sufficiently reliable to be recommended for broadacre cropping. [46]

5.11.6 Alternative forms of phosphorus

Phosphorus is not very mobile in the soil, so placing it at or near the seed at sowing is the most efficient way to ensure it is readily available to the growing plant.

Manures

Manures generally contain fairly low concentrations of nutrients. [47] While manure might seem cheaper by the tonne, available nutrients are released very slowly (only 50% of P is available in the first year); therefore, larger quantities are needed to supply enough nutrients for plants to use in the first year.

When using manures, always ensure that the manure being applied is analysed for available nutrients, because the nutrient content varies greatly depending on source and storage. [48]

The cost of transporting and applying manure may be greater than traditional fertiliser, and should be added to budget comparisons. [49]

5.12 Potassium

In high and medium rainfall areas of WA, many sandy soils have low native levels of potassium (K) and so K fertilisers are required. Deficiencies of K were first noted in the 1950s in pasture legumes. Although K levels in other areas were initially adequate for plant growth, continual K export in agricultural products over many decades has resulted in declining K reserves and increased incidence of K deficiency.

K is required for photosynthesis, transport of sugars, enzyme activation, maintenance of water status and regulation of stomata (openings that allow carbon dioxide into the leaf and water vapour out). Potassium is critical for controlling water balance within plant cells. [50]Potassium is a major nutrient that is increasingly required as soil reserves become depleted. [51] Factors such as soil acidity, soil compaction and waterlogging will modify root growth and the ability of crops to extract subsoil K.

A crop's requirement for K will increase as yield increases. High yielding cereal crops put large demands on soil nutrient supply, particularly on light to medium soils. While a soil with low K levels may be able to supply sufficient K for a low yielding crop, when the yield potential is increased, K deficiency may develop. Management factors that can affect crop demand for K include cropping intensity, crop yield levels,

46 GRDC (2012) Western Region Phosphorus Management. Fact sheet, https://grdc.com.au/Resources/Factsheets/2012/11/Crop-Nutrition-Phosphorus-Management-Fact-Sheet

47 James Easton, CSBP. Pers comm.

48 GRDC (2009) Profitable nutrient use starts with knowing the reserve. Targeted Nutrition at Sowing Fact Sheet, GRDC, 2009, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2010/02/targeted-nutrition-at-sowing

49 GRDC (2009) Profitable nutrient use starts with knowing the reserve. Targeted Nutrition at Sowing Fact Sheet, GRDC, 2009, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2010/02/targeted-nutrition-at-sowing

50 CSBP (2012) Soil and plant nutrition. https://csbp-fertilisers.com.au/research-trials/research/soil-and-plant-nutrition

51 DAFWA (2015) Diagnosing potassium deficiency in barley. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2539

increased nitrogenous and phosphatic fertiliser rates, sowing date, weed control, timeliness of operations and removal of stubble residues. [52]

Crop requirements for potassium change during the growing season. For cereals, potassium uptake is low at the beginning of the growing season when plants are small, but increases to a peak during the late vegetative and flowering stages. The soil must be able to supply the crop's potassium needs during periods of peak demand. [53]

Most heavy soils in WA contain adequate amounts of naturally occurring K for optimum crop and pasture growth. Sandy soils in higher rainfall areas are prone to K deficiency, as both native and fertiliser applied K is held poorly and is subject to leaching. Soil types of the west midlands in WA and southern sandy soils are commonly K deficient.

Until the early 1990s duplex soils rarely showed responses to potassium, however responses to the application of K on these soils are now well documented in the central and southern wheat-belt of WA. [54]

There does not appear to be a single mechanism by which K deficiency limits yield. Restricted K supply during early growth stages may be more harmful than later deficiency. Potassium deficiency can affect leaf area, dry matter produced in upper internodes and ears, the number of grains per head or the seed weight. The root system of K deficient plants may also be poorly developed. [55]

5.12.1 Deficiency symptoms

- Stunted plants with short, stout stems and pale yellow-green stems and leaves; appear limp or wilted
- Symptoms develop first on old leaves, but eventually move to younger leaves
- Tips of old leaves become dark yellow, moving down the edges of the leaves
- Yellow areas die and turn grey
- In some varieties, dark brown spots and streaks appear in the yellow areas or the green tissue close by; eventually the whole leaf becomes yellow, dies and turns pale to dark brown (Photo 6) [56]

52 DAFWA (1995) The Barley Book. Department of Agriculture and Food, Western Australia, http://researchlibrary.agric.wa.gov.au/bulletins/44/

53 DAFWA (1995) The Barley Book. Department of Agriculture and Food, Western Australia, http://researchlibrary.agric.wa.gov.au/bulletins/44/

54 Soil Quality (2017) Potassium fact sheet, http://www.soilquality.org.au/factsheets/potassium

55 DAFWA (1995) The Barley Book. Department of Agriculture and Food, Western Australia, http://researchlibrary.agric.wa.gov.au/bulletins/44/

56 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

Photo 6: *Barley leaf on the right shows adequate potassium nutrition; the others show inadequate K.* [57]

Source: Noel Grundon, QDPI

Similar symptoms

Nitrogen deficiency also shows yellowing of oldest leaves, but leaf death occurs much more rapidly with K deficiency.

Boron toxicity is similar, although symptoms usually occur later in crop development than K deficiency.

Contributing factors

Sandy soils with leaching potential can contribute to K deficiency. A history of high removal of hay stubble and/or grain will deplete K. [58]

5.12.2 Critical levels and inputs

Potassium soil tests are reported as exchangeable K (meq/100 g or cmol/kg) or, in the case of a Colwell-K test, as mg available/kg. Research is under way to improve definition of critical soil-test K levels.

Soil test levels in the range of 50 to 100 mg K/kg (Colwell K soil test) would indicate a maintenance application of K is required. Soils with Colwell K values >100 mg K/kg are unlikely to require applications of K.

Large amounts of potassium (K) can move out of the soil through leaching or plant uptake, especially in high rainfall (>750 mm), sandy areas. Potassium can also be removed by hay or windrow burning.

Testing for soil K in both the 0–10 and 10–30 cm layers is advisable. Tissue testing is a great tool for identifying K requirements after initial soil testing and K applications.

Potassium fertilisers can be side-banded at planting, drilled in pre-plant, or broadcast and cultivated in fallow or even prior to a preceding crop. The residual value of K fertiliser is excellent, so sporadic applications at higher rates can be an effective

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DAFWA (2015) Diagnosing potassium deficiency in barley.

57 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

58 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

alternative to lower rates with each crop. However, K banded in the seed row can affect germination if applying >12 kg K/ha.

Once K fertility of the surface layers has been restored, deep application of K fertilisers is best for maintaining soil productivity. A proportion of the deep K taken up by the crop is returned to the soil surface in the litter and crop stubble, which replenishes the K fertility of these surface layers. [59]

5.13 Sulfur

Much of WA is dominated by sandy soils characterised by low amounts of organic matter and a poor ability to retain water and nutrients. Fertilisers are a critical part of WA agriculture, and crops and pastures grow poorly without the addition of nutrients.

Previous widespread use of superphosphate (which contains 10% S) means sulfur (S) deficiency is rare in WA cereal crops. Early deficiency is occasionally seen in crops growing on sandy soils in wetter areas but plants generally recover without any yield loss. Continual use of compound fertilisers that contain little or no S will increase the risk of sulfur deficiency. [60]

Sulfur deficiencies have become more common over the past few decades with the increased use of fertilisers lacking S, such as All Phos (triple superphosphate or TSP), monoammonium phoshate (MAP) and diammonium phosphate (DAP).

As with N and P, most of the S in the soil is in organic forms. Hence, soils with low amounts of organic matter are more prone to S deficiency.

Organic S must be mineralised into sulphate before it can be taken up by plant roots. Sulphate is relatively mobile in soils and can be leached out of the rooting zone during winter.

Sulfur has an important role in the formation of proteins and is essential for the production of chlorophyll. [61]Sandy-textured soils in WA are naturally low in S and applied S is readily leached from the top 10 cm, especially in high rainfall areas.

The use of fertilisers containing S somewhat masks the low levels of S present in the soil, however the introduction of more sensitive crops such as canola and the change to compound fertilisers that are low in S, has increased the frequency of S deficiency seen in crops. High rainfall can leach sulfate from the root zone early in the growing season, leaving young crops deficient. Other factors that can induce deficiency in crops include sub-soil constraints such as acidity, sodicity and hardpan, and the level of N in the soil can limit the crop's ability to access subsoil sulfate.

Most S present in the soil is bound in organic compounds but plants can only take up the mineral sulfate form. Cultivation releases S held in organic matter. In no-till systems soil organic matter breaks down slowly, releasing mineral S for crop use. Sulfur mineralisation is low in cooler months, as is root exploration, which can cause temporary deficiency in crops, seen as patches that disappear when the soil temperature increases. Mineralisation is higher in the warmer months and under moist soil conditions. Sulfate adsorption occurs in the soil layers below 10 cm, which can make a significant contribution to crop growth once crop roots have reached the subsoil.

The rate of sulfate leaching is highly variable, depending on seasonal conditions and the water holding capacity of the soil, and is closely related to the rate of nitrate leaching. These two nutrients are best considered together when planning fertiliser applications at seeding and post-seeding to compensate for the movement of these nutrients down the profile.

MORE INFORMATION

GRDC (2011) Current nutrition issues in the cropping zone of Southern Australia. GRDC Update Paper.

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

60 DAFWA (2015) Diagnosing sulfur deficiency in cereals. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1998

61 CSBP (2012) Soil and plant nutrition. https://csbp-fertilisers.com.au/research-trials/research/soil-and-plant-nutrition

Sulfur nutrition in cropping systems is usually managed through the application of P or N fertilisers containing S, however if additional S is required, the most common sources of applied S are gypsum and ammonium sulfate. [62] The most commonly used S fertilisers are NPS and NPKS products. [63]

Gypsum is often preferred as it contains about 16–18% S, is relatively inexpensive and, unlike ammonium sulfate, is not acidifying. There are other fertilisers with varying N:S ratios achieved by blending ammonium sulfate with urea creating a product that absorbs water from the atmosphere, making it difficult to store and handle. [64]

However, depending on the sulphate of ammonia source, when granular ammonium sulphate is used, handling characteristics are acceptable. [65]

On sandy soils in WA only 15% of applied S remains one year after application in the top 0.5 m. [66] In the low to medium rainfall parts of the state, the residual value of S is much greater than this. [67]

In contrast, Gypsum-S applied to pasture grown on a non-leaching clay loam in WA has achieved a residual benefit on dry matter production for up to 3 years when applied at 34 kg S/ha. [68]

5.13.1 Deficiency symptoms

- Crops grow poorly, lack vigour and mature more slowly, resulting in reduced tillering, low grain yields and protein
- Initially all leaves are pale green, but old leaves turn darker green (Photo 7 and Photo 8)
- Youngest leaves turn pale yellow and eventually white, with the whole leaf affected not just the area between the veins
- Leaves generally do not die even when they have turned white
- Old leaves remain green
- In some varieties, margins and sheaths of old leaves become red or purple-red [69]

In severe deficiencies, the upper leaves are yellow to white in colour, with the lower leaves remaining pale green. Tiller number will also be reduced. [70]

Similar symptoms

Nitrogen deficiency symptoms are similar, with yellowing, but N deficiency occurs in the oldest leaves first rather than the whole plant.

Contributing factors

Low soil fertility (organic matter) and cold wet conditions reduce S mineralisation and uptake. Acid sandy soils are subject to S leaching. Commonly used starter fertilisers DAP and MAP are fertilisers such as DAP and MAP are low in S. [71]

62 GRDC (2015) Sulfur strategies for western region, https://www.grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region/Details

63 James Easton, CSBP. Pers comm.

64 GRDC (2015) Sulfur strategies for western region, https://www.grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region/Details

65 James Easton. CSBP. Pers comm.

66 GRDC (2015) Sulfur strategies for western region, https://www.grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region/Details

67 James Easton, CSBP. Pers comm.

68 GRDC (2015) Sulfur strategies for western region, https://www.grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region/Details

69 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

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

71 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

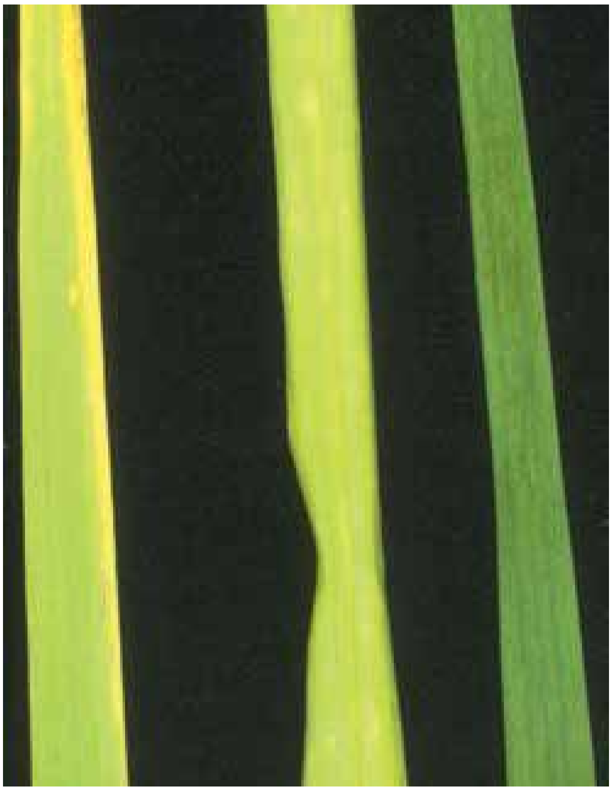

Photo 7: *Sulfur-deficiency symptoms on barley leaves (left and middle); adequate nutrition (right).*

Source: Hungry Crops, DAF Qld

Photo 8: *Sulfur-deficient barley plant (left); plant with adequate nutrition (right).*

Source: Noel Grundon, DAF Qld

MORE INFORMATION

G Anderson et al. (2013) Soil sulfur—crop response calibration relationships and criteria for field crops grown in Australia. CSIRO Publishing.

5.14 Micronutrient deficiencies

Micronutrient deficiencies can be difficult to diagnose and treat. However, by knowing the soil type, crop requirements and seasonal conditions, and using diagnostic tools and strategies, effective management is possible.

Key points:

- Significant yield losses can occur from trace element deficiencies before any visual symptoms become obvious
- The only reliable way to know a barley plant's trace element status is to tissue test
- Soil type is useful in determining the risk of micronutrient deficiencies.
- Soil testing is a poor indicator of trace element availability in WA
- Tissue testing is an accurate way to diagnose a suspected micronutrient deficiency
- When tissue-testing, the appropriate tissues should be sampled at the right time. In WA, whole tops are recommended. Plant nutrient status varies according to plant age, variety and weather conditions
- The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small
- When applying fertiliser to treat a suspected deficiency, leave a strip untreated. Either a visual response or tissue testing can confirm whether the micronutrient was limiting [72]

5.14.1 Zinc

Zinc deficiency has become more common in young barley plants emerging in drying soil but this deficiency is usually transitory and disappears when rainfall re-wets the topsoil. [73]

Zinc is essential for protein and consequently important for enzyme function in many different tissues.

Deficiency symptoms appear as oily grey-green patches in the centre of leaves. Young leaves are most affected. Deficiency is typically associated with alkaline soils over a wide range of textures. Lime and gypsum can reduce Zn availability.

Critical tissue concentrations in the youngest expanded blade of barley are <14 mg/kg. [74] Zinc supplements can be applied with fertiliser as Zn oxide, chelated Zn or Zn sulfate. The products can also be used for foliar applications. Product efficacy varies with the time and placement of application. [75]

Deficiency symptoms (Photo 9 and Photo 10):

- Plants are stunted with short, thin stems and usually pale green leaves
- Young to middle leaves develop yellow patches between the mid vein and the edge of the leaf, extending lengthways towards the tip and base of the leaf
- These areas eventually die turning pale grey or brown
- Plants take on a water- or diesel-soaked appearance
- Affected areas may remain separate or join, with the death of the entire central leaf area, while the tip, base and margins remain green
- With severe deficiency, yellow areas and grey-brown lesions develop on the leaf sheath, resulting in reduced tillering with no or little grain produced

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72 GRDC (2013) Micronutrients. Crop Nutrition Fact Sheet GRDC, November 2013, http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients

73 DAFWA (2015) Diagnosing zinc deficiency in barley. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2540

74 R Norton (2014) What's new with zinc; maybe just some critical reminders. GRDC Update Papers, 11 February 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Whats-new-with-zinc-maybe-just-some-critical-reminders

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

- Maturity is delayed. Mature plants are a dull grey colour compared with a bright yellow appearance of a healthy crop

Similar symptoms

The fungal disease yellow leaf spot has similar symptoms.

Contributing factors

Application of some herbicides (especially Group B) makes the problem worse. Zinc deficiency occurs on many soil types but is most severe on highly alkaline clay soils and very infertile siliceous sands, yellow gravelly sands, yellow earths, highly alkaline peat soils and highly alkaline coastal sands. [76]

Photo 9: *Zinc deficiency in barley.*

Photos: DAFWA

Photo 10: *Zinc deficiency symptoms on barley leaves.*

Source: DAFWA

76 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

5.14.2 Copper

Most soils in WA are Cu deficient in their natural state. Copper is essential for pollen formation and has a role in formation of chlorophyll and lignification (cell wall strength). Deficiency causes sterile pollen, which, in turn causes poor grain formation and high yield losses. [77]

Wheat and barley are more responsive to Cu than canola.

Deficiency is common in sandy soils that are low in organic matter, as well as where there are high levels of iron (Fe), Mn or Al in the soil. Critical tissue levels have been reported as <1.5 mg/kg in the youngest expanded blade in wheat. [78]

Deficiency symptoms in barley are depicted in Photo 11 and Photo 12.

In the paddock:

- Before head emergence, deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green healthy crop
- After head emergence, mildly affected areas have disorganised wavy heads Severe patches have white heads and discoloured late maturing plants
- Symptoms are often worse on sandy or gravelly soils, where root-pruning herbicides have been applied and recently limed paddocks

On the plant:

- Significant yield losses can occur from Cu with no visual symptoms
- Youngest growth is affected first and most severely
- The first sign of Cu deficiency before flowering is growing point death and tip withering, and/or bleaching and twisting of up to half the length of young leaves
- The base of the leaf can remain green
- Old leaves remain green and seemingly healthy
- Tiller production may increase but they die prematurely
- Heads may be white and withered or have a rat-tail appearance
- Maturity is delayed and very late tillers may be present
- Stems are weaker, although in less severe cases, plants heads may be more erect. Severely deficient plants have few immature heads on weak and dirty stems [79]

Similar symptoms

Drought stress, frost, take-all and Mo deficiency have similar symptoms. Boron and Ca deficiency also cause shoots to wither.

Contributing factors

Intensive cropping rotations with grain legume crops can contribute to deficiency. Additional N fertiliser can exacerbate the severity of the deficiency (crop still appears N-deficient). [80]

77 DAFWA (2015) Diagnosing copper deficiency in barley. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2534

78 R Norton (2014) Trace elements: copper and manganese. GRDC Update Papers, 20 August 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Trace-elements-copper-and-manganese-their-role-requirements-and-options

79 DAFWA (2015) Diagnosing copper deficiency in barley. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2534

80 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

Photo 11: *Copper deficiency n barley: head sterility causes delayed maturity.*

Source: DAFWA

Photo 12: *Copper deficiency symptoms on barley leaves.*

Source: Hungry Crops, DAF Qld

Photo 13: *Copper deficiency in barley: severely affected plants have no grain.*

Source: DAFWA

Photo 14: *Deformed barley heads indicating copper deficiency.*

Source: Nigel Wilhelm, SARDI

Alleviation

Copper can be applied as an additive to fertilisers, or as foliar spray as Cu sulfate, Cu oxychloride or chelated Cu. [81] However, the effectiveness of his strategy depends upon incorporation. Banding liquid Cu fertilisers at seeding can also be relatively effective. [82] One foliar spraying at booting may still be necessary in dry years.

5.14.3 Boron

Boron deficiency is rare in cereals in WA and will impact broadleaf crops such as lupin and canola before affecting cereals like wheat and barley. Boron does not easily move around the plant therefore a deficiency is most likely to be seen in the younger tissues first. [83]

Boron toxicity

Boron is essential for plants, but in some soils, it accumulates to toxic levels. Symptoms are yellowing and death of leaf tips, starting on the oldest leaves first (Photo 15). Symptoms often do not appear in early vegetative growth and are more extreme in a drying soil.

Similar symptoms

Spot-type net blotch has similar symptoms but is not soil-type specific.

Contributing factors

Boron toxicity can occur with high boron levels in subsoil and when growing B-intolerant varieties. [84]

Photo 15: *Symptoms of boron toxicity on barley leaves: Hamelin (left), Mundah (right).*

Source: DAFWA

MORE INFORMATION

Soil Quality (2017) Boron–Western Australia. Fact sheet.

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

82 James Easton, CSBP. Pers comm.

83 DAFWA (2015) Diagnosing boron deficiency in barley. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-boron-deficiency-barley

84 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

5.14.4 Manganese

Liming programs and increasing water repellence is increasing the incidence of manganese (Mn) deficiencies in WA. [85]

Manganese deficiency

Key points:

- Manganese is a common enzyme cofactor for chlorophyll and photosynthesis
- Deficiency symptoms are often preceded by wilting and then chlorosis of younger leaves, often at the base of the leaf
- Deficiency is mainly a problem on soils with high organic matter, and those with free lime present. It may be toxic at low pH (<5)
- For cereals, tissue concentrations of <12 mg Mn/kg in the youngest mature leaf or <20–30 mg/kg in whole tops are considered deficient
- In some cases, foliar Mn can be more efficient than soil-applied Mn, because the latter can result in Fe or phosphate precipitates [86] However, there are cases where two to three foliar applications are required to overcome deficiencies and where soil applied Mn is very effective [87]
- Chelated formulations are also available, but they are expensive

Symptoms

- Deficiency often appears as patches of pale, floppy plants in an otherwise green, healthy crop
- Pale green stripes usually develop on young leaves and blotches develop that may have a thin brown rim (Photo 16)
- Leaves are weak and tear easily
- Tillering is greatly reduced with extensive leaf and tiller death (Photo 17). With extended deficiency, the plant may die
- Surviving plants produce fewer and smaller heads

Photo 16: *Manganese deficiency symptoms.*

Source: Nigel Wilhelm, SARDI

85 James Easton, CSBP. Pers comm.

86 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

87 James Easton, CSBP. Pers comm.

Photo 17: *Manganese deficiency in barley (left); adequate (right).*

Source: Nigel Wilhelm, SARDI

Similar symptoms

Zinc deficiency causes patches of pale stunted plants but not they are not 'floppy'.

Contributing factors

Deficiency tends to occur on coastal alkaline soils and high PRI, water repellent gravels associated with wandoo powderbark wandoo, brown and blue mallet, and blue mallee vegetation.

Manganese deficiency is worsened by dry soil, high soil pH, alkaline fertilisers and root pruning herbicides (particularly groups A and B).

MORE INFORMATION

DAFWA (2015) Diagnosing manganese deficiency in barley.

Treatment

Manganese deficiency is controlled by:

- Foliar spray
- Acidifying ammonium nitrogen fertilisers can reduce manganese deficiency by lowering pH and making manganese more available to growing crops
- Manganese fertiliser is effective but expensive as high rates and several applications are required to generate residual value [88]

5.14.5 Molybdenum

Key points:

- Molybdenum is important for nitrate reductase activity in all plants
- Deficiency symptoms are similar to those of N deficiency
- Availability increases with high soil pH, and deficiencies are common on acid soils, especially in high-rainfall areas
- Levels <0.075 mg/kg in the youngest fully emerged leaf indicate deficiency [89]

88 DAFWA (2015) Diagnosing manganese deficiency in barley. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2536

89 DAFWA (2015) MyCrop. Diagnosing molybdenum deficiency in cereals. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-molybdenum-deficiency-cereals

- Very small quantities (50 g Mo/ha) applied with fertiliser are usually sufficient, usually in the form of Mo trioxide. Sodium or ammonium molybdate can be used as sprays [90]

Photo 18: *Wheat grown without (left) and with molybdenum (symptoms are similar in barley).*

Source: Snowball and Robson 1988

Symptoms (Photo 18):

- Symptoms are difficult to detect in the field, particularly early in the season
- At low levels of N, the crops are pale with some limpness
- As N levels increase, symptoms become more specific with all but the oldest leaves pale being green with adequate to high levels of N
- Middle leaves have a speckled flecking or yellow stripes
- Leaves appear limp and water-stressed
- Tip scorching of old leaves apparent at high N levels
- Severe deficiency causes delayed maturity and empty heads

Similar symptoms

Stem and head frost damage causes late tillering and shrivelled grain.

Contributing factors

Factors include acidic soils, moderate to high levels of available soil N, and soils high in Fe and Al oxides. [91]

5.14.6 Magnesium

Western Australian agricultural soils, particularly acidic sands, are inherently low in magnesium but deficiency is rare in broadacre crops. [92]

Symptoms (Photo 19):

- Young crops have poor growth with pale yellow leaves
- In more mature crops, plants are stunted with thin spindly stems and pale yellow foliage is marked with necrotic lesions

90 Incitec Pivot. Molybdenum fact sheet. Fertfacts. Incitec Pivot, http://www.incitecpivotfertilisers.com.au/en/Agronomy/~/media/Files/IPF%20Migration/FertFacts/MolybdenumFS/MolybdenumFSV3IIPLLM15102009.ashx

91 GRDC (2014) Winter cereal nutrition: The Ute Guide. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2007/05/uteguide-wintercerealnutrition

92 DAFWA (2015) Diagnosing magnesium deficiency in barley. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-magnesium-deficiency-barley

- Old leaves develop elongated grey to brown spots near the edges, usually near the mid-section of the leaf. Lesions spread rapidly towards the tip and base of the leaf
- With severe deficiency, old leaves turn brown and die

Similar symptoms

Potassium and N deficiency symptoms include pale plants starting from the oldest leaf, but no grey-brown lesions.

Contributing factors

In WA, Mg levels are normally improved with applications of lime. [93]

Photo 19: *Magnesium deficiency symptoms in barley.*

Photos: Noel Grundon, DAF Qld

MORE INFORMATION

DAFWA (2015) Diagnosing magnesium deficiency in barley.

93 James Easton, CSBP. Pers comm.

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

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.

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.

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

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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

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

VIDEO

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

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

MORE INFORMATION

IWM Section 5: Tactics

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

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

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

Insect control

Barley like other cereals can be damaged by a wide range of insect pests and other arthropod pests including blue oat mite (*Penthaleus* spp.), redlegged earth mite (*Halotydeus destructor*), Bryobia mites (*Bryobia* spp.), Balaustium mites, cutworms, aphids, earwigs, armyworms, *Helicoverpa* spp., pasture webworm, pasture cockchafers, grass anthelids, lucerne flea (*Sminthurus viridis*), leaf hoppers, slugs, snails, millipedes, slaters and locusts (Table 1 and Table 2). Mice may also cause damage.

For current chemical control options, refer to the Pest Genie or Australian Pesticides and Veterinary Medical Authority (APVMA) websites. [1]

Table 1: *Pests that pose a risk to cereal crops* [2]

High risk	Moderate risk	Low risk
Soil insects, slug and snails		
Some crop rotations increase the likelihood of soil insects: Cereal sown into a long-term pasture phase High stubble loads Above-average rainfall over summer–autumn History of soil insects, slugs and snails Summer volunteers and Brassica weeds will increase slug and snail numbers Cold, wet establishment conditions expose crops to slugs and snails	Information on pest numbers prior to sowing from soil sampling, trapping and/or baiting will inform management Implementing integrated slug management strategy (burning stubble, cultivation, baiting) where there is a history of slugs Increased sowing rate to compensate for seedling loss caused by establishment pests	Slugs and snails are rare on sandy soils
Earth mites		
Cereals adjacent to long-term pastures may get mite movement into crop edges Dry or cool, wet conditions that slow crop growth increase crop susceptibility to damage History of high mite pressure	Leaf curl mite populations (transmitters of Wheat streak mosaic virus) can be increased by grazing and mild wet summers	Seed dressings provide some protection, except under extreme pest pressure

1 DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

2 DAF Qld (2016) Winter cereals. IPM guidelines. Department of Agriculture and Fisheries Queensland, http://ipmguidelinesforgrains.com.au/crops/winter-cereals

High risk	Moderate risk	Low risk
Aphids		
Higher rainfall areas where grass weeds are present prior to sowing—higher risk of Barley yellow dwarf virus (BYDV) transmission by aphids Wet summer and autumn promotes survival of aphids on weed and volunteer hosts	Wet autumn and spring promote the growth of weed hosts; when weed hosts dry off, aphids move into crops Planting into standing stubble can deter aphids landing Using seed dressings can reduce levels of virus transmission and delay aphid colonisation Using synthetic pyrethroids and organophosphates to control establishment pests can kill beneficial insects and increase the likelihood of aphid survival	Low rainfall areas—lower risk of BYDV infection High beneficial activity (not effective for management of virus transmission)
Armyworms		
Large larvae present when the crop is at late ripening stage	High beneficial insect activity (particularly parasitoids) Rapid crop dry-down	No armyworm present at vegetative and grain-filling stages

Table 2: *Incidence of pests of winter cereals* [3]

	Crop stage			
	Emergence	**Vegetative**	**Flowering**	**Grainfill**
Wireworms	Damaging	Present		
Cutworm	Damaging			
Blackheaded cockchafer	Damaging	Present		
Earth mites	Damaging	Present		
Slugs, snails	Damaging			
Brown wheat mite		Damaging		
Aphids	Present	Damaging	Present	Present
Armyworm		Present–damaging	Present	Damaging
Helicoverpa armigera				Damaging

Identification and reporting tools

Accurate pest, weed and disease identification is vital for appropriate pest or disease management. Most importantly it helps identify possible new threats to agriculture and the environment.

3 DAF Qld (2016) Winter cereals. IPM guidelines. Department of Agriculture and Fisheries Queensland, http://ipmguidelinesforgrains.com.au/crops/winter-cereals

MORE INFORMATION

GRDC (2015) Insect pests—resistance, virus vectors and lessons from 2014. GRDC Update Paper.

GRDC Ute Guides: Insects

cesar: Insect gallery

cesar: PestFacts: Grass anthelids

NIPI: Insect identification aids

PestFacts South Australia

Effective farm biosecurity practices help to underpin the quality of Western Australian (WA) grain and have the potential to deliver the surveillance data required to demonstrate country or regional area freedom from pests.

Continued productivity depends on access to new and existing grains markets and this hinges on being able to provide quality evidence of freedom from certain harmful pests. Smart 'apps' and mobile technologies can offer growers advanced diagnostic capabilities to help document pests or quantify the spread of insecticide resistance.

DAFWA has developed a number of apps which can be used to report the presence of unfamiliar pests and diseases. [4]

Click on the links below to download an app, or to make an online report.

MyPestGuide–allows you to identify pests and report your observations. DAFWA will respond to reports within 48 hours.

PestFax Reporter–report observations of pests and diseases in your paddocks to the Western Australian PestFax newsletter editor.

Alternatively, please contact DAFWA's Pest and Disease Information Service on 1800 084 881 or email info@agric.wa.gov.au.

Use Table 3 and Table 4 to identify damage caused by key pests, and to assess risk and determine control measures for establishment pests. The MyCrop barley app is also helpful for diagnosis of pest, disease and nutrition.

Table 3: *Crop damage pest identification key—cereals* [5]

Damage to crop	Pest
Leaves or plants cut off and lying on the ground or protruding from small holes next to plants; brown caterpillars (up to 15 mm long) with black heads, present in web-lined tunnels; wheat or barley seeded into grassy pasture paddocks.	Webworm
Large portions of plants eaten and some leaves or plants cut off. Smooth, fat caterpillars up to 40 mm long usually found just under the soil surface and may curl up when disturbed.	Cutworms
Green material removed in irregular patches from one surface of the leaf leaving white window-like areas; paddocks may appear white; presence of dumpy, wingless, greenish yellow insects, which spring off plants when disturbed.	Lucerne flea
Leaves shredded or chewed, slimy trails.	Slugs and snails
Smooth, shiny brown animals with curved pincers at the end of the body. Damage irregular, often similar to slug damage, mostly in patches, when sown in heavy stubble.	Earwigs
Minor leaf chewing; presence of dark brown to black caterpillars up to 60 mm long with two yellow spots near posterior end.	Pasture day moth
Presence of tiny eight-legged (nymphs have six legs) velvety black or brown crawling creatures with orange-red legs, found on plants or on soil surface at the base of plants.	Redlegged earth mite, blue oat mite, Balaustium mite
Plants stunted and dying at emergence and up to tillering; chewing of seed and stem below ground; white legless larvae up to 7 mm long present near point of attack.	Spotted vegetable weevil or Desiantha weevil

4 R McCauley et al. (2016) The world's first Biosecurity Blitz (2015)–Lessons learned about reporting plant pests for the WA grains industry. GRDC Grains Research Update, 29 Feb–01 Mar 2016, http://www.giwa.org.au/2016researchupdates

5 GRDC (2012) I spy. Insects of Southern Australian Broadacre Farming Systems Identification Manual and Education Resource. GRDC, https://grdc.com.au/resources-and-publications/all-publications/bookshop/2012/11/i-spy

Damage to crop	Pest
Plants stunted or dying; roots eaten; slow-moving, soft bodied insects usually in a 'C' shape, cream-coloured apart from head and visible gut contents; found near roots.	Cockchafers, African black beetle
Plants yellowing and withering; on light soils mostly on coastal plain; stems underground shredded; presence of elongated, cylindrical insects up to 75 mm long, first pair of legs adapted for digging.	Sandgropers
Green and straw-coloured insect droppings like miniature square hay bales on ground; cereal heads on ground; some chewing of leaves and seed heads of weeds such as ryegrass. Smooth, fat caterpillars up to 40 mm long, with three stripes on collar behind head; found at base of plants or climbing plants.	Armyworm
Seeds chewed but heads not severed; caterpillars up to 40 mm long, sparsely covered with small bumps and bristles, may be various shades of green, yellow, orange or brown; found on seed heads.	Native budworm and related species
Presence of many grey-green insects approx. 2 mm long, with or without wings, on upper portions of stem. If heavy infestations, plants stunted; sticky with secretions, possibly black mould growing on secretions.	Aphids
Damage in fine pale dots in wriggly or zigzag lines. Yellow to green, 3 mm long wedge-shaped sucking insects that jump sideways when disturbed.	Leafhoppers

Table 4: *Establishment pests of the southern region—risk assessment and management* [6]

Pre-season	Pre-sowing	Emergence	Crop establishment
Earth mites and lucerne flea			
Assess risk. High risk when: • history of high mite pressure • pasture rotating into crop • susceptible crop being planted (e.g. canola, pasture, lucerne) • seasonal forecast for dry or cool, wet conditions that slow crop growth If risk is high: • ensure accurate identification • use TIMERITE® (redlegged earth mites only) • heavily graze pastures in early–mid spring	If high risk: • use an insecticide seed dressing on susceptible crops • plan to monitor more frequently until crop establishment • use higher sowing rate to compensate for seedling loss • consider scheduling a post-emergent insecticide treatment If low risk: • avoid insecticide seed dressings (especially cereal and pulse crops) and plan to monitor until crop establishment	Monitor susceptible crops through to establishment using direct visual searches. Be aware of edge effects; mites move in from weeds around paddock edges If spraying: • ensure accurate identification of species before deciding on chemical • consider border sprays (mites) and 'spot' sprays (lucerne flea) • spray prior to winter egg production to suppress populations and reduce risk in the following season	As the crop grows, it becomes less susceptible unless growth is slowed by dry or cool, wet conditions

6 NIPI (2014) Establishment pests—Southern Region. 'Best bet' IPM strategy. NIPI IPM Workshops, http://ipmworkshops.com.au/wp-content/uploads/BestBet_EstablishmentSouth2014.pdf

Pre-season	Pre-sowing	Emergence	Crop establishment
Slugs			
Assess risk. High risk when: • high stubble load • annual average rainfall >450 mm • history of slug infestations • canola being planted • summer rainfall • heavy clay soils	If high risk: • burn stubbles • cultivate worst areas • remove weeds in paddocks and along fence lines at least 8 weeks before sowing • deploy shelter traps before sowing • sow early to get crop established prior to cold conditions • use soil compaction at sowing (e.g. press-wheels) • bait at or after sowing prior to emergence	Assess risk. High risk under cold conditions and with slow plant growth Use shelter traps or directly search at night when slugs are active to confirm slugs as the cause of seedling loss If slug pressure is high, successive baiting may be necessary. Monitoring will guide bait use	As the crop grows, it becomes less susceptible unless growth is slowed by cool conditions. Resowing may be required if plant stands are unsatisfactory
False wireworm and true wireworm			
Assess risk. High risk when: • history of wireworm pressure • soils high in organic matter • high stubble and summer–autumn litter cover	Conduct direct visual search for adult beetles over summer and autumn. Search (in soil) for beetle larvae 2 weeks prior to sowing. If high risk: • reassess crop choice or timing of sowing • consider an insecticide seed dressing (particularly fipronil) or in-furrow treatment • use soil compaction at sowing (e.g. press-wheels) • consider higher sowing rate to compensate for seedling loss	Limited options for control once crop is sown. Consider resowing severely affected areas of crop	Damage to established crops is rare
Beetles			
Assess risk. High risk when: • sowing crop into pasture, especially with a high clover content • previous history of scarab damage to crop in that field • wetter than average seasons • minimum or no tillage • Under high pressure: • spray African black beetle adults in spring • avoid overgrazing pastures	Dig soil within paddock to determine incidence of scarab larvae. If high risk: • cultivate land • avoid sowing grass pastures • use soil compaction at sowing (e.g. press-wheels) • consider higher sowing rate to compensate for seedling loss	Assess risk. High risk when dry conditions slow plant growth Limited options for control once crop is sown. Larvae of most species do not emerge from the soil For blackheaded pasture cockchafer, spray around heavy dews or light rainfall, which will trigger larval activity	Resowing may be an option, but some species have a two-year life cycle, so larvae can persist through winter into spring. ID will guide this decision
Others—e.g. earwigs, slaters, millipedes, weevils			
Assess risk. High risk when: • history of high pest pressure • minimum/no-tillage • high stubble load • heavier soils Monitor in spring using shelter traps, direct searches and/or pitfall traps	If high risk: • burn stubbles • cultivate worst areas • use cracked wheat baits • avoid sowing canola	Monitor susceptible crops through to establishment. Directly search at night to confirm pest species as the cause of seedling loss (Note: large numbers of these pests can be found in paddocks without causing crop damage)	Damage to established crops is rare

MORE INFORMATION

NIPI IPM Workshops: Decision making for insect management in grain crops

7.1 Integrated pest management

Pests are best managed using integrated pest management (IPM). Careful planning prior to sowing, followed by regular monitoring of crops after sowing, will ensure that potential problems are identified and, if necessary, treated early.

IPM uses a range of management tactics to keep pest numbers below the level where they cause economic damage. It focuses on natural regulation of pests, particularly by encouraging natural enemies, and on using broad-spectrum chemicals as a last resort. IPM relies on having pests and beneficial insects correctly identified, monitoring the crop regularly, and making strategic control decisions according to established damage thresholds. [7]

Identification

Accurate identification of beneficial and pest species is fundamental to IPM. For example, there are four easily confused pest mite species commonly found in most grain production regions of Australia. Despite their similarity in appearance, these mites – redlegged earth mite (RLEM), blue oat mite, clover or Bryobia mite and Balaustium mite – differ in their response to commonly used pesticides.

It is important to understand the biology and life cycle of target pests and beneficial species. Knowing when populations are likely to increase or decrease can affect control decisions.

Natural enemies

Beneficial species, sometimes referred to as 'natural enemies', help to control invertebrate pests as part of a successful IPM strategy. Many beneficial species occur naturally and populations can be encouraged by reducing pesticide use.

Monitor populations

Populations of pest and beneficial insects need to be monitored prior to seeding, during the growing season, and after control treatments to establish success or the need for re-treatment.

Ideally, each species should be recorded by life stage and detailed records should help identify trends in species' population growth or decline, over time. Details to be recorded for a paddock should include:

- key pests and beneficial species, ideally by life stage
- insect location within a paddock
- crop health and growth stage
- paddock pesticide history
- weed presence
- weather patterns

Control decisions

Whether beneficial species will effectively control pests depends on the comparative numbers of different life stages present. Small predators cannot control large pests, large predators will devour a large quantity of small pests and some predators attack specific pest types. Small predators can be useful when they attack pests in their early (smaller) life stages or when multiple pests attack larger prey.

It is important to establish if there are enough pests present to warrant control and to relate these figures to an economic threshold. This the point where the balance between pests and beneficial insects is likely to result in economic crop damage greater than the cost of control. [8]

7 K Hertel, K Roberts, P Bowden (2013) Insect and mite control in field crops. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

8 GRDC (2009) Integrated Pest Management. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/bookshop/2009/12/integrated-pest-management-fact-sheet-national

Manage resistance

Emerging pests, like snails and slugs, and rising occurrences of insecticide resistance in RLEM, has heightened the need for better strategies to protect WA crops and pastures.

Climatic conditions, continuous cropping and stubble retention has resulted in a rise in the risk of insecticide resistance with some pests, such as RLEM.

In 2016, 56 properties reported populations of RLEM resistant to synthetic pyrethroids, such as bifenthrin, with three of these properties also resistant to omethoate. A further four properties have been identified with RLEM resistance to omethoate and the first with resistance to chlorophyrifos.

The repeated cumulative exposure of RLEM to the same insecticides was the main factor behind resistance developing. Every time a broad-spectrum insecticide is used to control pests, such as weevils, caterpillars and aphids, RLEM also receive a dose of this insecticide, despite not necessarily being the direct target.

Decreasing the need to spray can be done by reducing the occurrence of pests. This can be achieved by staying on top of the 'green bridge' and removing plant material that could provide feed and a habitat to support pests over summer into the growing season. [9]

MORE INFORMATION

DAFWA (2016) Diagnosing cereal aphids.

DAFWA (2016) Aphid feeding damage to cereal crops.

DAFWA (2016) Insecticides for the control of cereal aphids.

GRDC (2015) Crop Aphids Back Pocket Guide.

GRDC: Ute Guides Online.

7.2 Aphids

Aphids are vectors of *Barley yellow dwarf virus* (BYDV), a major problem in wet areas in western growing regions.

Seasonal conditions have a major effect on aphid populations, which are ultimately controlled by natural predators. However aphid populations can do considerable damage before other insects or heavy rains reduce or eliminate them. [10] Therefore, growers should consider seed treatment prior to sowing and/or in-crop foliar pesticide spraying to control aphids.

When winged cereal aphids fly into crops from grass weeds, pasture grasses or other cereal crops, colonies start to build within the crop. In Australia, all aphids in a cereal crop are females and are able to give birth to live young without mating. The immature aphid nymphs have several growth stages and moult at each stage into a larger individual. Sometimes the delicate, pale cast skins can be seen near colonies. When host plants become unsuitable or overcrowded, winged aphids, called alataes, develop and migrate to other crops or plants.

Three types of aphid are commonly found in barley crops and they can all carry BYDV. In trials, aphids have been found to attack different parts of the barley plant at different times.

7.2.1 Oat or wheat aphid (*Rhopalosiphum padi*)

Oat or wheat aphids can be found on all cereals and in most years of high infestation they are the most abundant species. A vector of BYDV, the oat aphid colonises the lower portion of the plant with infestations extending from the plant's base up onto the leaves and stems as the crop starts to elongate (Photo 1, Table 5). Mature adults are about 2 mm long and may have wings that are dark green and rounded or pear-shaped. Juveniles are paler and smaller and both are characterised by a dark reddish patch on the tip of the abdomen.

9 DAFWA (2016) Increasing pressure for Integrated Pest Management. Media Release, 8 March 2016. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/5402

10 L Price (2010) Aphids in cereals. Goondiwindi Grains Research Update, Northern Grower Alliance, March 2010, http://www.nga.org.au/results-and-publications/download/19/grdc-update-papers-pests/aphids-in-winter-cereals/grdc-adviser-update-paper-goondiwindi-march-2010-.pdf

Photo 1: *Heavy infestation of oat aphids (Rhopalosiphum padi).*

Source; Evan Collins

Table 5: *Oat or wheat aphid management summary* [11]

Scientific name	*Rhopalosiphum padi*
Description	Adults are 2 mm long, olive-green to black with a red rust patch at the rear end and may have wings. Antennae extend to half the body length. Nymphs are similar but smaller. Very similar to corn aphids
Distribution	An introduced species found in all states of Australia
Crops attacked	Barley, wheat and oats
Life cycle	Produces many generations through the growing season. Winged and non-winged forms occur
Damage	Aphids feed directly on stems, leaves and heads; in high densities they cause yield losses and plants may appear generally unthrifty. This type of damage is rare throughout the grainbelt. Aphids can spread BYDV in wheat and barley
Monitoring and action level	Aphids can affect any crop stage but are unlikely to cause economic damage to cereal crops expected to yield <2 t/ha (for virus damage) and <3 t/ha (for direct feeding). Consider treatment if there are 10–20+ aphids on 50% of the tillers
Control	Chemical control: Apply a foliar insecticide in late winter or spring to avoid direct damage to tillers and heads. To prevent losses from BYDV in virus-prone areas, control aphids early in the cropping year. Prevent infestation by applying a seed dressing to early-sown wheat crops and a foliar insecticide in high-pressure years if necessary (predator friendly). For current chemical control options, see Pest Genie or APVMA Cultural control: Controlling the green bridge (i.e. controlling weeds over the summer fallow) is an effective control measure to prevent aphid survival into the next season
Host-plant resistance	In virus-prone areas, use resistant plant varieties to minimise losses due to BYDV
Natural enemies	Predation by hoverflies, lacewings and ladybeetles, and parasitism by wasps can reduce aphid populations, but this does not happen in every season. Heavy rain may reduce aphid populations significantly

11 DAF Qld (2011) Oat aphid, wheat aphid. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/oat-aphid,-wheat-aphid

7.2.2 Corn aphid (*Rhopalosiphum maidis*)

Corn aphids are more likely to be found in barley crops, but do also occur in wheat. Corn aphids are more rectangular than oat aphids. Adults are 2 mm long and may have wings. The legs and antennae are typically darker than the green-blue body, which sometimes has a waxy appearance (Photo 2). Colonies generally develop within the furled emerging leaves of tillers, particularly the rolled-up terminal leaf, and they can be difficult to see. Corn aphids can be important vectors of BYDV if they arrive early in crops (Table 6).

Photo 2: *Corn aphids (Rhopalosiphum maidis).*

Source; Qld DAF

Table 6: *Corn aphid management summary* [12]

Scientific name	*Rhopalosiphum maidis*
Description	Up to 2 mm long, light to dark olive-green with a purple area at the base of small tube-like projections at the rear of the body. Adults are generally wingless. Antennae extend to about one-third of body length. Nymphs are similar, but smaller
Similar species	Other species of aphids
Distribution	An introduced species, probably Asiatic in origin, found in all states of Australia
Crops attacked	Sorghum, maize, winter cereals and many grasses Life cycle on cereals: A parthenogenetic species that undergoes many generations through the growing season. Both winged and non-winged forms occur
Damage	In cereal: Aphids feed on stems, leaves and heads, and in high densities cause yield losses. However, this type of damage is uncommon in the cereal belt Risk period: Most prevalent on cereals in late winter and early spring. High numbers often occur in years with an early break in the season, mild weather in autumn and early winter provides favourable conditions for colonisation and multiplication
Monitoring	Estimate percentage of plants infested and percentage of leaf area covered by aphids
Action level	Aphids are unlikely to cause economic damage to cereal crops expected to yield <3 t/ha. To avoid damage by direct feeding, consider treatment if there are ≥10–20 aphids on 50% of the tillers
Chemical control	Chemical control is cost-effective. See Pest Genie or APVMA for current control options Conservation of natural enemies: A range of parasitoids and predators will help reduce aphid populations. Predators of aphids include: ladybird larvae, damsel bugs, big-eyed bugs and the larvae of green lacewings and hoverflies. Wasp parasitoids mummify and kill aphids

7.2.3 Thresholds for control

Inspect for aphids throughout the growing season by monitoring leaves, stems and heads, as well as exposed roots. Choose six, widely spaced positions in the crop and at each position examine five consecutive plants in a row.

Research is under way into damage thresholds and control options for cereal aphids. Some research indicates that aphid infestations can reduce yield by ~10% on average. Current notional thresholds suggest that control is warranted when there are >10–20 aphids on 50% of the tillers.

The decision to control aphids on winter cereals depends on the size of the aphid population and the duration and timing of the infestation. Controlling aphids during early crop development generally results in a recovery of the rate of root and shoot development but there can be a delay. Aphids are more readily controlled in seedling and pre-tillering crops, which are less bulky than post-tillering crops. Corn aphids in the terminal leaf tend to disappear as crops come into head, and other species usually decline in abundance about this time as natural enemy populations build up.

Always determine the level of natural enemy activity when making control decisions about aphids. The thresholds above are for aphid damage—there is no threshold for BYDV transfer.

12 DAF Qld (2010) Corn aphid. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/corn-aphid

7.2.4 Russian wheat aphid (*Diuraphis noxia*)

As yet Russian wheat aphid (RWA) has not been detected in WA. However, following the widespread outbreak of RWA in South Australia and Victoria in 2016, WA growers are encouraged to be vigilant in monitoring for RWA and to send photos of any suspect populations to DAFWA.

Russian wheat aphid is potentially a more severe pest than other aphids.

While aphid feeding damage generally results in yield losses of up to 10 per cent, in overseas crops Russian wheat aphid has caused yield losses of more than 80 per cent.

Unlike other aphids, Russian wheat aphids inject a toxin into susceptible crops, like wheat and barley, which can severely retard growth or under heavy infestations, kill the plant.

7.3 Armyworm (*Leucania convecta*)

Armyworms are the caterpillar stage of certain moths (Photo 3), and can occur in large numbers, especially after good rain following a dry period. Larvae shelter in the throats of plants or in the soil and emerge in spring to feed on the leaves of all winter cereals, particularly barley and oats. Leafy cereal plants can tolerate considerable feeding, and control in the vegetative stage is seldom warranted unless large numbers of armyworms are distributed throughout the crop or are moving in a 'front', destroying young seedlings or completely stripping older plants of leaves. The most serious damage occurs when larvae feed on the upper flag leaf and stem node as the crop matures, or in barley when the older larvae start feeding on the green stem just below the head as the crop matures.

Photo 3: *Common armyworm (Leucania convecta).*

Source; Qld DAF

Infestations are evident as scalloping on leaf margins from the feeding of older larvae. They target the stem node as the leaves become dry and unpalatable because the stem is often the last part of the plant to dry. One large larva can sever up to seven heads of barley a day and larva/m^2 can cause a grain loss of 70 kg/ha/day (Table 7). Larvae take ~8–10 days to develop through the final, most damaging instars, with crops susceptible to maximum damage for this period (Table 8).

Check for larvae on the plant and in the soil litter under the plant. The best time to do this is late in the day when armyworms are most active. Alternatively, look around the base of damaged plants where the larvae may be sheltering in the soil during the day. Using a sweep net (or swinging a bucket), check a number of sites throughout the paddock. Sweep sampling is particularly useful early in an infestation when larvae are small and actively feeding in the canopy. One full sweep with a net samples the equivalent of 1 m^2 of crop.

Early recognition of the problem is vital because cereal crops can be almost destroyed by armyworm in just a few days. Although large larvae do the head lopping, controlling smaller larvae that are still leaf-feeding may be more achievable. Before using chemical intervention, consider how quickly the larvae will reach damaging size, and the development stage of the crops. Small larvae take 8–10 days to reach a size capable of head-lopping, so if small larvae are found in crops nearing full maturity–harvest, spray may not be needed. In contrast, small larvae in late crops that are still green and at early seedfill may reach a damaging size in time to significantly reduce crop yield.

Control is warranted if the armyworm population distributed throughout the crop is likely to cause the loss of 7–15 heads/m^2. Many chemicals will control armyworms, however their effectiveness often depends on good penetration into the crop in order to contact the caterpillars. Control may be more difficult in high-yielding, thick-canopied crops, particularly when larvae are resting under soil at the base of plants. Larvae are most active at night; therefore, spraying in the afternoon or evening may produce the best results. If applying sprays close to harvest, be aware of relevant withholding periods.

Biological control agents may be important in some years. These include parasitic flies and wasps, predatory beetles and diseases. *Helicoverpa* NPV is not effective against armyworm. [13]

Table 7: *Value of yield loss incurred by armyworm larvae (1 or 2/m^2) per day, based on various values for grain and an estimated loss, given 1 larva/m^2, of 70 kg/ha*

Value of grain (A$/t)	Value of yield loss ($) per ha per day	
	1 larva/m^2	2 larvae/m^2
$140	$9.80	$19.60
$160	$11.20	$22.40
$180	$12.60	$25.20
$200	$14.00	$28.00
$220	$15.40	$30.80
$250	$17.50	$35.00
$300	$21.00	$42.00
$350	$24.50	$49.00
$400	$28.00	$56.00

Considering these results, and the relatively low cost of controlling armyworm, populations of >1 large larva/m^2 in ripening crops warrant spraying

Source: DAF Qld

13 DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

Table 8: *Armyworm management summary* [14]

Scientific name	*Leucania convecta*—common armyworm
Description	Common armyworm: First-instar larvae are about 1 mm long. From the second instar, stripes develop along the top and sides of the larva and become more distinct as the larva grows. The mature larva grows up to 40 mm in length and has three characteristic pale stripes on the head, collar (segment behind the head) and tail segment. They are smooth-bodied with no distinct hairs. The body also has lateral stripes. The forewings of the moth have a wingspan of about 40 mm and are fawn or buff-coloured
Similar species	Adults of the common and northern armyworms may be confused. Genitalia dissections by a specialist are required to separate the species. The larval stages likely to be encountered in cereals are similar in appearance
Distribution	Common armyworm is a native Australian species, recorded in New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia
Crops attacked	Common armyworm damages barley, oats, wheat, native pasture grasses and perennial grass seed crops
Life cycle	Common armyworms have three generations per year. The winter and spring generations damage cereals. Moths fly into cereal crops and lay their eggs in the folds of dried or drying leaves on grasses or cereals. Females lay up to 1,000 eggs in irregularly shaped masses, cemented in tight folds of foliage. Eggs hatch as little as 3–4 days after laying and young larvae, with the assistance of wind, disperse through the crop on fine silken threads. The larvae feed on leaves and stems. Larvae usually develop through six instars but sometimes seven. Indicative development times at constant temperature are: egg-laying to hatch, 7 days at 20°C and 2.5 days at 30°C; larval stages (including pre-pupal stage) 34.2 days at 20°C and 17.2 days at 30°C. Larvae pupate in the soil. Pupal stage lasts 20.1 days at 20°C and 10.1 days at 30°C. Development time from neonate to adult emergence is 61 days at 20°C and 41 days at 30°C (Smith 1984)
Risk period and damage	Risk period: The greatest risk to cereals is spring. Moth flights occur in September and October, and the later-stage larvae damage cereals often in the weeks prior to harvest. The mature larval stages of the winter generation will sometimes march in cereal crops in late winter and cause serious damage to crops, particularly on the edges of paddocks. Crops directly seeded into standing stubbles are susceptible to severe defoliation during the vegetative stage as the winter generation matures Damage: There are two distinct periods for economic damage. The first, defoliation during early vegetative development, is less common than the second through ripening. In southern Australia, the cereal head stays green later and armyworms feed along the heads and damage grain rather than excising the whole head

14 DAF Qld (2010) Common, northern and sugarcane armyworms. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/armyworm-overview/common,-northern-and-sugarcane-armyworms

Monitoring and action level	Large numbers of armyworm moths are attracted to farm lights on warm nights in September and October. This provides the first warning of potential problems in cereals. Armyworm larvae are difficult to find in cereals crops because they hide at the base of plants or under clods of soil during the day. Search at the base of plants and under clods of soil to estimate the number of larvae per m^2. Presence of green–yellow pellet-shaped droppings of the larvae on the ground is usually a reliable sign of larvae. Monitor for larvae at dusk with a sweep net; sweep-netting during the day can be unreliable Action level is 2 larvae/m^2 for barley
Control	Chemical control: A range of insecticides is registered for armyworm control in cereals. Insecticides should target larvae 10–20 mm long. Larvae >20 mm long can be difficult to kill and may require higher rates of insecticide application. If possible, spray late in the day because larvae are active at night. See Pest Genie or APVMA for current control options Cultural control: Windrowed or swathed crops dry out rapidly, rendering them unattractive for the feeding of armyworm larvae. They are also less susceptible to wind damage (head shattering)
Natural enemies	Armyworm larvae are attacked by a number of parasitoids that may be important in reducing the intensity of outbreaks. However, when armyworms are in numbers likely to cause damage, parasitoids are unlikely to give timely control. Predators include green scarab beetles, populations of which increase dramatically in inland Australia in response to abundant noctuid larvae induced by favourable seasons. Other predators include the predatory shield bugs and perhaps common brown earwigs. Fungal diseases are recorded as causing mortality of armyworm

MORE INFORMATION

DAFWA (2016) Management of armyworm in cereal crops.

7.4 *Helicoverpa* spp.

Helicoverpa spp. are frequently found in winter cereals, usually at levels too low to warrant control, but occasionally numbers may be sufficiently high to cause economic damage. *H. punctigera* is widespread in southern Australia and common on pulse crops and canola, but rarely found on cereal crops. *H. armigera* (Photo 4) can occasionally be found grazing wheat and barley heads. [15]

Larvae tend to graze on the exposed tips of a large number of developing grains, rather than totally consuming a low number of whole grains, thus increasing the potential losses. Most (80–90%) of the feeding and crop damage is done by larger larvae (the final two instars).

15 GRDC (2012) Approaches to key insect pests of southern and western grains. Southern and Western Regions. Insecticide Management and Invertebrate Pest Identification. GRDC Fact Sheet, http://rawbrown.com.au/pdf/agribusiness/Fact-Sheet-1.pdf

Photo 4: *Helicoverpa armigera.*

Source: Qld DAF

Photo 5: *Native grubworm*

Source: DAFWA

7.5 Mites

7.5.1 Blue oat mite (*Penthaleus* spp.)

Blue oat mites (Photo 6) are important pests of seedling winter cereals. Adults and nymph mites pierce and suck leaves, resulting in silvering of the leaf tips. Feeding causes a fine mottling of the leaves, similar to the effects of drought. Heavily infested crops may have a bronzed appearance, and severe infestations cause leaf tips to wither and can lead to seedling death. Damage is most likely during dry seasons when mites in large numbers heighten moisture stress; control may be warranted in this situation.

Check from planting to early vegetative stage, particularly in dry seasons, monitoring several sites throughout the field (Table 9). Blue oat mites are most easily seen in the cooler part of the day or in cloudy conditions as they shelter on the soil surface when conditions are warm and sunny. If pale-green or greyish irregular patches appear in the crop, check for blue oat mite at the leaf base.

Where warranted, foliar application of registered insecticide may be cost-effective. Check the most recent research to determine the likely susceptibility of blue oat mite to the available registered products. Cultural control methods can contribute to reducing the size of the autumn mite population (e.g. cultivation, burning, controlling weed hosts in fallow, grazing and maintenance of predator populations).

Eggs laid in the soil hibernate throughout winter; therefore, populations of the mite can build up over a number of years and cause severe damage if crop rotation is not practised. Using control tactics solely in spring will not prevent the carryover of eggs into the following autumn.

Predators of blue oat mites include spiders, ants, predatory beetles and the predatory *Anystis* mite and snout mite. Blue oat mites are also susceptible to infection by a fungal pathogen (*Neozygites acaracida*), particularly in wet seasons. [16]

Photo 6: *Blue oat mite (Penthaleus sp.).*

Source: A Weeks, cesar

16 DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

Table 9: *Management summary for blue oat mite* [17]

Scientific name	*Penthaleus major, P. falcatus, P. tectus*
Description	Adults are 1 mm long and have eight legs. Adults and nymphs have a purplish-blue, rounded body with red legs. They move quickly when disturbed. The small red area on the back distinguishes it from the redlegged earth mite
Similar species	Redlegged earth mite Briyobia Mite Balastium mite
Crops attacked	Mainly a pest of cereals and grass pastures, but will feed on pasture legumes and many weeds
Damage	Adults and nymphs pierce and suck on leaves resulting in silvering of the leaf tips in cereals. When heavy infestations occur, the leaf tip withers and the seedling can die
Monitor	Check from planting to early vegetative stage, particularly in dry seasons. Most easily seen in the late afternoon when they begin feeding on the leaves
Control	Foliar applications of insecticides may be cost-effective if applied within 2 to 3 weeks of emergence in autumn. Using control tactics solely in spring will not prevent the carryover of eggs into the following autumn. For current chemical control options see Pest Genie or APVMA. Blue oat mites have higher natural tolerance to a range of pesticides.
Natural enemies	Thrips and ladybirds

Blue oat mite often co-exists with redlegged earth mites (Photo 7). Refer to Table 10 for how to distinguish it from other mites that may be found with it.

Photo 7: *Redlegged earth mites (Halotydeus destructor) often coexist with blue oat mites (Penthaleus sp.).*

Source: DAFWA

17 DAF Qld (2010) Blue oat mite. Mites in field crops. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/mites-overview/blue-oat-mite

Table 10: *Distinguishing blue oat mite from similar mites*

Condition	Similarities	Differences
Redlegged earth mite	Size, body colour and plant damage	The redlegged earth mite has no red dot on its back
Balaustium mite	Immature balaustium mites are the same size as blue oat mites and cause similar plant damage	Adult balaustium mites are twice the size of adult blue oat mites
Bryobia mite	Plant damage and leg colouration	The front legs of the bryobia mite are much larger and it causes whitish trails on the leaf surface

Source: DAFWA

7.5.2 Redlegged earth mite (*Halotydeua destructor*)

Redlegged earth mites (RLEM) are a common sap-sucking pest of crops and pastures (Photo 8, Photo 9 and Photo 10) with canola and peas are particularly susceptible. They often co-exist with blue oat mites (Table 16).

Photo 8: *An emerging lupin plant being attacked.*

Source: DAFWA

MORE INFORMATION

DAFWA (2014) Earth mites – economic considerations for management.

Photo 9: *Young barley plant showing typical symptoms of cuticle stripping and tip withering.*

Source: DAFWA

Photo 10: *A young canola plant being attacked.*

Source: DAFWA

Table 11: *Management summary for redlegged earth mite*

Scientific name	*Halotydeua destructor*
Description	Adults are 1 mm long with a black body and eight red-orange legs. Newly hatched mites are 0.2 mm long with a pinkish-orange body and six legs.
Similar species	Blue oat mite Briyobia mite Balastium mite
Development	RLEM originate in South Africa, and usually have three generations per season, with the last generation producing thick-walled over-summering eggs in spring Over-summering eggs hatch in autumn, stimulated by adequate moisture and at least seven days of temperatures below 20°C Mite damage tends to be worse after pastures than after cereal crops
Damage	Feeding causes a silver or white discolouration of leaves and distortion. If damage is severe the plants shrivel and die. Damage is more severe when seedlings are stressed (e.g. cold waterlogged or under very dry conditions).
Monitor	Check paddock for mites in the spring and again before seeding. Check for mites on the ground and on leaves and for plant damage from emergence to early vegetative stage, particularly in late-sown crops
Control	Spray only if required. RLEM have been detected that have resistance to synthetic pyrethroids. Rotate chemical groups in and between seasons, as this will help to reduce resistance. Use insecticide seed treatments for crops and new pastures with moderate pest pressure rather than spraying whole paddocks. This allows for smaller quantities of pesticide to be used that will directly target plant-feeding pests. Control weeds before seeding, particularly in crops sown in late autumn or winter when RLEM are likely to hatch before seeding. At least one week of bare soil can 'starve out' most of the mite population before crops are sown. Control weeds in the crop and along fence lines that provide habitat for mites. A weed-free crop will have few mites and over-summering eggs to carry through to the following season. Controlled grazing of pasture paddocks that will be cropped the next year will reduce mite numbers to levels that are almost as effective as chemical sprays. Sustained grazing of pastures throughout spring should maintain them at levels below 2 t/ha. Feed On Offer (dry weight) will restrict mite numbers to low levels. Apply insecticides to paddocks that are to be cropped during spring to prevent RLEM populations producing over-summering eggs. This will minimise the pest population for the following autumn. TIMERITE® is a free package that provides a date in spring for a spray application to stop female RLEM from producing over-summering eggs. Look at cropping rotations to decrease reliance on pesticides. The risk is generally highest if paddocks have been in long-term pasture (with high levels of broad-leafed plants) where mite populations have been uncontrolled. Lower risk Paddocks that generally do not require mite control are often those that follow a weed-free cereal or chickpea crop.

MORE INFORMATION

GRDC (2016) RLEM resistance management strategies. Ground Cover Radio 122.

GRDC (2012) Crop Mites Back Pocket Guide.

DAFWA (2016) Prevent redlegged earth mite resistance.

DAFWA (2015) Diagnosing redlegged earth mite.

DAFWA (2014) Earth mites: economic considerations.

7.5.3 Balaustium mite (*Balaustium medicagoense*)

Balaustium mite (Photo 11) is a sucking pest of crops but usually outgrow damage unless stressed.

Photo 11: *Balaustium mite*

Source: DAFWA

Table 12: *Management summary for Balaustium mite* [18]

Scientific name	*Balaustium medicagoense*
Description	Adults are up to 2 mm and uniformly red-brown with stout hairs covering the body. Very young mites are bright red.
Similar species	Blue oat mite Briyobia mite Redlegged earth mite
Development	Balaustium mites originate in South Africa, usually have two generations per season and do not require cold temperatures to stimulate egg hatching. Eggs hatch when there is sufficient moisture. Mite damage is common in early-sown crops in years with summer rain and green bridge.
Damage	Balaustium mites typically attack leaf edges and leaf tips of plants and affected barley plants look moisture stressed. They are most common in early break seasons where green material was left on the paddock prior to sowing. Damage is characterised by distorted cupped cotyledons that may appear leathery.
Control	Early control of summer and autumn weeds, especially capeweed and grasses, will help to control populations Applications of SP at the highest registered rate provides control. Organophosphates are not effective against this pest

18 DAFWA (2015), Diagnosing blue oat mite. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-blue-oat-mite

7.6 Lucerne flea (*Sminthurus viridis*)

Lucerne flea is an important pest of establishing crops. It is identified by its behaviour of jumping between plants rather than flying. Early-sown crops are more at risk of attack. Frequent crop inspection from the time of emergence and early control measures are important because of the impact of seedling vigour on crop performance. Ensure there is sufficient monitoring to detect localised patches or 'hot spots'. Seek advice on management and spray strategies. [19]

Photo 12: *Adult lucerne flea (Sminthurus viridis).*

Source: cesar

7.6.1 Seasonal development and symptoms

Lucerne fleas hatch following periods of good, soaking autumn–winter rainfall and can cause significant damage to emerging crops and pastures at this time of year. They can also cause considerable damage to older crops if numbers build up under favourable conditions throughout the season.

Table 13: *Management summary for Lucerne flea*

Scientific name	*Sminthurus viridis*
Description	Adult lucerne fleas are globular, wingless insects, 2–3 mm long with green, brown and yellow markings (Figure 11). They appear yellow-green to the naked eye, although their globular abdomens are often a mottled pattern of darker pigments. They make jumping movements when disturbed. Nymphs resemble the adults except in size. [18]
Crops attacked	Lucerne fleas have a wide host range. They will attack most broadacre crops, including canola, lucerne, pastures, cereals and some pulses. Feeding results in distinctive transparent 'windows'. They are generally a problem in regions with heavier soil types.
Damage	The cells of the upper surface of leaves and cotyledons are eaten, resulting in small 'windows' in the leaves. Severe infestations cause skeletonised leaves, with only the more fibrous veins remaining. This damage is quite distinctive and can be used to help identify lucerne flea as the key pest.

19 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/winter-crop-variety-sowing-guide

20 CropPro. Lucerne flea. Pests in canola. CropPro, http://www.croppro.com.au/cb_pages/pests_in_canola_-_in_crop.php?category_id=2374

Monitor	Crops should be inspected frequently. Crops are most susceptible to damage—at and immediately following—emergence. Paddocks are most likely to have problems when they follow a weed-infested crop or a pasture in which the lucerne flea has not been controlled.
Control	Several options are available to growers for controlling the lucerne flea. Foliar insecticides can be applied around 3 weeks after lucerne fleas have been observed in a newly emerged crop. This will allow for further hatching of over-summering eggs but will be before lucerne fleas reach the adult stage and begin to lay winter eggs. If spraying is required, do not use synthetic pyrethroids. They tend to target heavier soil types first. In paddocks where damage is likely, a border spray may be sufficient to prevent movement of lucerne fleas into the crop from neighbouring paddocks. Lucerne fleas are often distributed patchily within crops; therefore, spot-spraying is generally all that is required. Do not blanket-spray unless the infestation warrants it. For current chemical control options see Pest Genie or APVMA.

7.6.2 Management

Only when infestations are severe should lucerne flea be sprayed. In some instances, spot spraying with registered chemicals may be adequate. Several natural enemies such as mites, beetles and spiders prey on lucerne fleas, and blanket spraying is harmful to these natural control agents. Seed dressing can also be a useful technique to prevent damage by lucerne flea. [21]

Snout mites which have orange bodies and legs) are effective predators of lucerne fleas, particularly in pastures, and can prevent pest outbreaks. The complex of beneficial species (including snout mites) should be assessed before deciding on control options. [22]

Several options are available to growers for controlling the lucerne flea. Foliar insecticides can be applied around 3 weeks after lucerne fleas have been observed in a newly emerged crop. This will allow for further hatching of over-summering eggs but will be before lucerne fleas reach the adult stage and begin to lay winter eggs. If spraying is required, do not use synthetic pyrethroids.

They tend to target heavier soil types first. In paddocks where damage is likely, a border spray may be sufficient to prevent movement of lucerne fleas into the crop from neighbouring paddocks. Lucerne fleas are often distributed patchily within crops; therefore, spot-spraying is generally all that is required. Do not blanket-spray unless the infestation warrants it.

MORE INFORMATION

Agriculture Victoria: Lucerne flea.

NIPI IPM Guidelines: Lucerne flea in winter seedling crops.

NIPI: I Spy Manual. Lucerne flea (section 4, pp. 63–64).

7.7 Webworm (*Hednota* spp.)

Webworm larvae are leaf-chewing pests of seedling wheat and barley (Photo 13, Photo 14 and Photo 15). They can be distinguished from cutworm as demonstrated in Table 13.

21 CropPro. Lucerne flea. Pests in canola. CropPro, http://www.croppro.com.au/cb_pages/pests_in_canola_-_in_crop.php?category_id=2374

22 cesar (2010) Lucerne flea. PestFacts south-eastern, Issue 3, 21 May 2010. cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2010/pestfacts-issue-no-3-21st-may-2010/lucerne-flea/

Photo 13: *Webworm larva.*

Source: DAFWA

Photo 14: *Webworm adult.*

Source: DAFWA

Photo 15: *Webworm larva on seedling.*

Source: DAFWA

Table 14: *Management summary for Webworms* [23]

Scientific name	*Hednota* spp.
Description	Insect larvae • Brown caterpillars up to 15 mm long with black heads, which hide in web-lined tunnels during day (Figures 12 and 14). Insect adult • Small tan-coloured moths with wings that fold closely around the body in a nearly vertical position (Figure 13), enabling the moth to blend with its surroundings. • Larvae tend to be more common on of the edge of patches.
Development	Caterpillars hatch from eggs laid in the grass in autumn and feed throughout the winter. • Spring and summer are passed in the tunnels as resting-stage caterpillars. After this, they pupate and emerge as adult moths, which are about 10 mm long and may be seen flying in large numbers on autumn nights.
Monitor	Check emerging crops seeded into areas where fine, dry grasses were prevalent during autumn for signs of damage. Careful digging at the base of recently damaged plants may reveal web-lined tubes containing caterpillars, or a search at night may reveal feeding activity.

23 DAFWA (2015) Diagnosing webworm. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-webworm

Damage	Paddock • Bare patches in emerging crops. Plant • Oldest leaves have been removed or are severed at ground level. • Leaves are scattered on the ground or pulled into web-lined holes near the plants.
Control	Spraying insecticide • If 25% of plants are being seriously damaged at or just after emergence, spraying should not be delayed, as continued feeding will kill many plants and result in bare ground or thin areas. • Webworm eggs will not be laid in large numbers or survive well in a bare paddock or in stubble. • Three-week fallow at the break of the season will starve any caterpillars present.

7.8 Cutworm (*Agrostis* spp.)

Cutworm caterpillars feed on leaves and stems near ground level, with stems often chewed through and 'cut' to ground level (Photo 16).

Photo 16: *Cutworm damage.*

Source: DAFWA

Photo 17: *Cutworm.*

Source: DAFWA

Photo 18: *Cutworm larvae can vary in colour.*

Source: DAFWA

Table 15: *Management summary for Cutworm*

Scientific name	*Agrostis* spp.
Description	Cutworm moths can fly large distances and favour bare or lightly vegetated areas for egg laying.
Similar species	Webworm, Armyworm
Monitor	Cutworm caterpillars are usually easily controlled with registered rates of SP chemicals (refer to currently registered products). Early and complete control of green bridge two weeks before planting will minimise survival of cutworm larvae. Check crops from emergence through to establishment. Larvae are usually just below the soil surface during the day and emerge to feed at night. Check the base of healthy or recently damaged plants adjoining damaged, bare or thin areas. Two large caterpillars per 0.5 m row of cereals can cause extensive damage.

Table 16: *Distinguishing from similar pests* [24]

Condition	Similarities	Differences
Webworm	Chewed seedlings leaving bare patches	Webworms are small brown caterpillars that pull leaves into web-lined burrows
Armyworm	Lop seedling stems at ground level	Armyworm has three prominent stripes behind the head

7.9 Pest slugs and snails

Slug and snail pests damage plant seeds (mainly legumes), recently germinated seeds, seedlings and leaves, and can be a contaminant of grain at harvest. [25]

7.9.1 Distribution of slugs and snails

Slugs are pests of crops, especially higher rainfall regions of WA.

Snails are found on all soil types. White Italian and vineyard snails prefer alkaline sandy soils; the small pointed snail is able to survive on all soil types, even acidic soils. Liming areas where there are snails will aid their survival.

The small pointed snails are only known to cause economic crop damage in high rainfall areas, whereas the vineyard and white Italian snails are known to cause crop damage in the Greenough Flats (the region between Dongara to Geraldton) and the Geraldton region.

7.9.2 Identification and habits of pest slugs and snails

Slugs

Black keeled slug (Milax gagates)

Black keeled slugs are 40–60 mm long, black to brown, with a ridge down their back (Photo 19).

MORE INFORMATION

DAFWA (2016) Cutworm: Pests of crops and pastures.

DAFWA (2014) Cutworm – Economic considerations for management.

24 DAFWA (2014) Diagnosing cutworm in cereal crops. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-cutworm-cereals

25 DAFWA (2015), Identification and control of pest slugs and snails for broadcare crops in Western Australia. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

This species burrows to a depth of 20 cm or more, surviving the heat of summer under the ground. Black keeled slugs re-emerge when conditions improve, such as after reasonable rainfall and when soil temperature decreases.

Photo 19: *Black keeled slug (bottom) and reticulated slug (top).*

Source: DAFWA

Snails

Small pointed (conical) snail (Prietocella barbara)

The small pointed snail has a conical shell with brown bands of varying width. It is usually less than 10 mm in length or diameter.

Small pointed snails are not restricted to alkaline soils. These snails survive the summer in many habitats—under leaf litter, under the soil surface (up to 50 mm), under stumps or stones—and they climb posts and vegetation. This behaviour of climbing up on vegetation makes it a contamination risk at harvest (Photo 20).

Photo 20: *Small conical snails on underside of a canola leaf.*

White Italian snail (Theba pisana)

White Italian snails are predominantly white, often with fine, brown, concentric lines of varying intensity (Photo 21). The body of the snail is creamy-white and the shell is 10–20 mm in diameter. The umbilicus (the hole about which the shell spirals) is partly obscured.

This species thrives in areas of alkaline sandy soils with high calcium content, mainly near the coast. Be aware of snails before liming paddocks, as lime aids survival.

It survives during summer off the ground on vegetation and posts, and is commonly found on green weeds. This over-summering behaviour of sealing itself on vegetation off the ground makes it a contamination risk of harvested grain.

Photo 21: *Different shell colours of white Italian snail.*

Source: DAFWA

Vineyard or common white snail (Cernuella virgata)

The vineyard snail resembles the white Italian snail in size and colouring (Photo 22). However, the umbilicus (the hole about which the shell spirals) of the vineyard snail is entire and not partly obscured as with the white Italian snail.

Like the Italian snail, this species thrives in areas of alkaline sandy soils with a high calcium content, mainly near the coast. It survives during summer off the ground on vegetation and posts. If lime is applied to paddocks where this snail is present, it will aid the survival of the population.

Photo 22: *Vineyard snail.*

Source: DAFWA

7.9.3 Damage

Snails are not known to damage seeds, but may damage germinated seeds close to the soil surface. However, slugs are not known to feed on ungerminated canola or cereal seeds.

Irregular pieces chewed from leaves and shredded leaf edges are typical of snail and slug presence.

Cereal crops are likely to survive damage by slugs and snails, while canola and lupins cannot compensate for the damage or loss of cotyledons. If cereals are deep sown into a fine, firm seedbed, the slugs and snails are not able to feed on the growing point and emerging crops may recover from damage after treatment.

Different species of slugs cause differing amounts of damage. Cereals are less likely to sustain damage from reticulated slugs than from black keeled slugs.

7.9.4 Snail and slug control

Control methods

The most effective control of pests involves combining cultural control measures alongside chemical and biological measures. Set a long-term goal to reduce slug and snail pests, rather than relying on a 'knee-jerk' reaction to an immediate problem.

Cultural control

Snails and slugs live in areas where abundant ground cover and vegetation provide ideal moisture levels and shelter. This is why they can be a problem on the edge of a crop with a weedy fence line. Good hygiene, weed control and removal of refuges can reduce the problem over time. Pest problems may increase in the short term after this process, as the pests will no longer have the weeds for food or shelter.

Cultivation of the ground not only kills pests directly, but provides a sterile habitat from which survivors flee. A short fallow period can improve this effect. Good hygiene will improve the value of other methods, especially baiting.

Control measures applied individually are unlikely to provide optimum control. An integrated approach needs to be considered to protect crops from damage by slugs and/or snails.

Monitoring

The key to effective control is monitoring. Monitoring regularly means pests can be detected early, ideally before seeding, as there are more control options available at this time. Once the crop has been seeded and germination is commencing, control options are limited to baiting. At this time crops should be examined at night for slug and snail activity.

It is best to look for slugs and snails on moist, warm and still nights. Fresh trails of white and clear slime (mucus) visible in the morning also indicate the presence of slugs or snails.

How to find slugs

An alternative method in a paddock is to place wet carpet squares, hessian sacks or tiles on the soil surface. They should be at least 32 cm by 32 cm (10% of a m^2). Place pellets under them. After a few days, count the number of slugs under and around each square. Multiplying by 10 will give an estimate of slugs per m^2. Table 17 gives an indication of thresholds.

A useful method to detect areas infested with slugs, prior to seeding or crop emergence, is to lay lines of slug pellets with a rabbit baiter. In infested areas, slugs are attracted to the freshly turned soil and pellets placed in the furrow. Very large numbers can be found dead or dying in the furrows or nearby. On sloping ground, furrows should be run along contours to reduce the risk of soil erosion in heavy rain.

How to find snails

Snails are usually found on stumps, fence lines and under stubbles. A good way to determine snail numbers on open ground is to use a 32 cm by 32 cm square quadrant and count all of the live snails in it. This is an area of 10% of a m^2 so multiplying by 10 will give an estimate of snails per m^2.

Consider control options if slug and snail numbers are above thresholds. [26]

MORE INFORMATION

DAFWA (2015) Identification and control of pest slugs and snails for broadcare crops in Western Australia.

DAFWA (2014) Snail and slug control.

GRDC (2013) Slug identification and management Fact sheet.

GRDC (2010) Snail Bash'em Burn'em Bait'em.

PestNotes: Small Pointed Snail

Table 17: *Suggested thresholds for control of slugs and snails in broadacre crops*

Species	Oilseeds	Cereals	Pulses	Pastures
Black keeled slug	1–2 per m^2	1–2 per m^2	1–2 per m^2	5 per m^2
Reticulated slug	1–2 per m^2	5 per m^2	1–2 per m^2	5 per m^2
Small pointed snail	20 per m^2	40 per m^2	5 per seedling	100 per m^2
Vineyard snail	5 per m^2	20 per m^2	5 per m^2	80 per m^2
White Italian snail	5 per m^2	20 per m^2	5 per m^2	80 per m^2

Please note: The above thresholds are from limited data. It is essential to carefully monitor crops as distributions of snails and slugs are patchy.

Source: DAFWA

7.10 Earwigs

7.10.1 European earwig (*Forficula auricularia*)

The European earwig (*Forficula auricularia*) (Photo 23) were first recorded in WA around 1990 and now can be found over much of the south-west of WA and in Perth.

Although the adults have wings, they seldom fly and are mainly spread by human activity. In recent years these earwigs have caused significant damage to broadacre and horticultural crops, as well as contaminating grain.

This section details the biology and management options for this pest.

26 DAFWA (2015), Identification and control of pest slugs and snails for broadcare crops in Western Australia. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

- Adults range from 12 to 24 mm long
- They have uniform brown bodies that are smooth and shiny with light brown or yellow legs, pincers (also called forceps) and 'shoulders'
- These earwigs have a flattened, elongated body with a reddish-brown head and slender, beaded antennae
- Pincers of male earwigs are long and curved, whereas those of females are almost straight
- Young earwigs, also called nymphs, look similar to adults but are smaller, paler and do not have wings

Photo 23: *European earwig: male (left), female (right).*

Source: DAFWA

7.10.2 Native earwigs

Native earwigs are widespread and feed mainly on leaf litter and other organic material and are not known to damage crops (Photo 24).

They are often solitary and will not be seen in the high numbers usually associated with pest populations of European earwigs.

Photo 24: *Native earwig: male (left), female (right). Note: the male has curved pincers.*

There are two native species commonly confused with European earwigs. *Carcinophora occidentalis* (no common name) has reddish-brown foreparts and legs, with a darker abdomen and pincers. *Labidura truncata* (common brown earwig) has similar colouring to the European earwig but can be distinguished from the European earwig by the orange triangle behind the head on the wing case (Photo 25).

Photo 25: *Common brown earwig (Labidura truncata).*

Source: DAFWA

MORE INFORMATION

[DAFWA (2016) Australian plague locusts: identification field guide.](#)

[DAFWA (2015) Monitoring insects and other crop pests.](#)

[DAFWA (2014) Locusts and grasshoppers – economic considerations for management.](#)

7.11 Locusts and grasshoppers

Locusts and grasshoppers are chewing pests that can cause complete defoliation if populations are high enough. In WA there are regular locust outbreaks in seasons following wet summers (every 4–5 years). Experience has shown damage to barley crops is usually minimal. In most cases barley crops have matured by the time the locusts are at their most damaging. Late maturing barley crops could be vulnerable to head loss due to locusts feeding on the stem below the head as this is the last part of the plant to ripen.

Table 18: *Management summary for locusts and grasshoppers* [27]

Description	Adult locusts are up to 40 mm long with a black spot on the tip of a clear hindwing, X-shaped mark behind the head and red shanks of the hind legs (Figure 35). Insect larvae Nymph locusts resemble adults but have dark shanks and lack wings
Development	Plague locusts are native insects that have two generations, in spring and autumn, and require green feed. Nymphs have five growth stages (instars). Over-summering eggs are laid in spring for the autumn generation, often in heavy soils. Green bridge feed is required for the autumn generation to lay sufficient eggs to pose a risk for crops in spring. Adults form swarms that can fly long distances and cause significant damage.
Damage	Leaves and stems have chewed pieces missing, with complete defoliation of plants in extreme cases. Established green crops tend to be avoided by hoppers, although the edges of crops can be damaged. Crops beginning to dry off when locusts begin to fly are susceptible to damage; locusts cause little if any damage to crops that have dried off.
Control	To achieve effective control, the best time to apply an insecticide is when locusts are hoppers. Treating small areas of dense masses of hoppers immediately after hatching can also be worthwhile, but will only control a relatively small proportion of the total number within a paddock and may involve several sprays as hatching times are staggered If locust swarms do form, they should be controlled when they first fly into an area where their feeding will cause damage. It is important to be aware of the likelihood of locusts flying onto your property and to stay vigilant Sprays must be applied directly onto the locusts and the vegetation on which they are feeding Barrier spraying to keep locusts out of an area is not effective

27 DAFWA (2014) Locusts and grasshoppers–economic considerations for management. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3495

Photo 26: *Locust adult.*

Source: DAFWA

Photo 27: *Locust nymph.*

Source: DAFWA

7.12 Desiantha or spotted vegetable weevil (*Steriphus diversipes*)

The larvae of Desiantha weevil attack cereal crops, especially along the south coast and in late plantings. Larvae feed underground on germinating seeds or stems and often kill plants or cause abnormal or stunted growth. They favour sand over gravel and sandy duplex soils.

Desiantha weevil larvae are white, legless, with orange-brown heads and are up to 6 mm long (Photo 28). Larvae remain under the soil and are difficult to locate, although some painstaking digging may reveal larvae close to plants. Adults are mottled grey-black weevils about 5 mm long with the typical weevil snout (Photo 28).

Photo 28: *Desiantha weevil larva (left) and adult (right).*

Source: DAFWA

Table 19: *Management summary for Desiantha or spotted vegetable weevil*

Scientific name	*Steriphus diversipes*
Description	Insect adult Flightless weevils are about 5 mm long, dark grey to black, and often have a mottled or spotted appearance Adults live on the soil surface but do not damage cereals Insect larvae White, legless grubs with yellow or orange-brown heads and up to 6 mm long
Monitor	Check germinating cereal crops, especially along the south coast and in late plantings, for poor emergence and discoloured and stunted plants
Damage	Paddock Patches of dead, weak or dying plants that are mainly found on sandy surfaced soils Symptom severity patterns can vary with practices that may alter weevil egg-laying preference, plant density, or plant nutrition Plant Larvae chew the swollen seed, bore into the underground stem of seedlings or tillers causing them to wither and die

MORE INFORMATION

DAFWA (2014) Desiantha weevil – economic considerations from management.

Control	Effective control of grass weeds in previous season and of green bridge following summer rain will minimise the risk of crop losses from desiantha The only in-crop treatment is to reseed with insecticide-coated seed

7.13 Cockchafers (*Sericesthis* spp.)

Cockchafer (scarab) larvae feed underground on organic material and some species are also serious pests of cereals. A number of species are found in WA; however, only a few actually cause crop damage. Cockchafer larvae can be found in high numbers and not cause crop damage (Photo 29).

Photo 29: *Scarab larvae.*

Photo 30: *Top: Scarab adult. Bottom: Scarab adults mating*

Table 20: *Management summary for Cockchafers*

Scientific name	*Sericesthis* spp.
Description	Larvae are found only in soil and are up to 12 mm long, creamy-white with a darker head and curled into a 'C' shape
Development	Cockchafers are native insects that occasionally reach damaging levels when conditions favour egg laying. The complete life cycle may take one or two years. Some species have a long larval stage that extends over 12–18 months. In most species the larva is active during late autumn and winter, then pupates in spring, with adults emerging in early summer. Feeding, mating and egg laying may occur throughout summer.
Monitor	Check newly emerged crops for underground damage and larvae in the soil
Damage	Larvae feed on underground plant parts, causing them to wither and die, potentially leading to large bare areas. Crops after pasture are more likely to be damaged, with damage worse near tree belts
Control	Cockchafers cannot be successfully controlled with insecticides post-crop emergence as they stay underground Insecticides can be mixed with seed or a higher seeding rate can be used if paddocks are known to have high populations of cockchafers

Table 21: *Distinguishing from other causes of damage*

Condition	Similarities	Differences
African black beetle	C-shaped grubs; lead to young plant death from chewed roots and crowns	African black beetle adults continue to chew plants throughout the season, fraying the lower stem and often only affecting individual tillers
Sandgropers	Early plant death from chewed roots and crowns	Sandgropers are large cricket-type insects that cause damage in the West Midlands; they continue to chew plants throughout the season and fray the lower stem

MORE INFORMATION

DAFWA (2015) Cockchafer damage to broadacre crops.

7.13.1 Rutherglen bug (*Nysius vinitor*)

The Rutherglen bug has traditionally only been a problem in emerging canola in WA, but in the last few years with wet summer/autumn there has been significant damage to young cereal crops growing post canola (or where there was high mintweed numbers over summer) and when an insecticide knockdown wasn't included with the weed knockdown. [28]

The Rutherglen bug is a native species that breeds on a range of native and weed hosts and is a pest of numerous crops across Australia. It is a small, fast moving bug that can build up to high numbers during the warmer months when suitable hosts are available. The pest occurs most commonly in late canola pod set and at windrowing.

28 Erin Cahill (2016) CSBP Pers comm.

Table 22: *Management summary for Rutherglen bug* [29] [30]

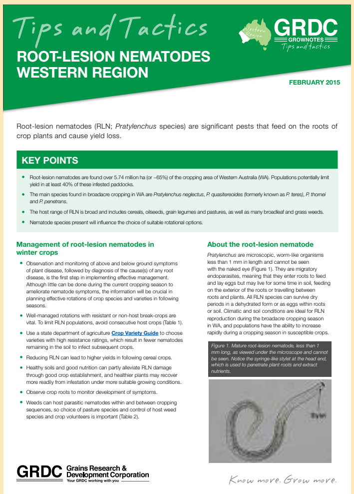
Scientific name	*Nysius vinitor*
Description	The adult RGB (Nysius vinitor) is a sapsucking insect; 4–6 mm long; mottled grey, brown and black in colour; with clear, silvery-grey wings folded flat over its back. It is often mistaken for grey cluster bug (Nysius clevelandensis), which is a close relative, but is a minor pest compared to RGB. The RGB nymph is wingless with a reddish-brown, pear-shaped body. It is more mobile than similar-looking aphids. Adult bugs breed on weeds and non-crop plants in inland Australia and need a green bridge to survive. During wetter winter–spring seasons, weeds in cropping regions can also be key breeding hosts. It is hard to predict which plants will drive RGB invasions in any one season. Adults generally stop breeding in late February as temperatures drop and days grow shorter.
Control	Damage of Rutherglen bugs can be reduced by parasitoids, controlling weeds and ploughing a deep furrow around emerging summer crops. There are several organophosphates and synthetic pyrethroids registered against Rutherglen bugs but these are disruptive to natural enemies. Insecticide applications will not guarantee a clean crop as Rutherglen bugs can readily reinvade a sprayed area. Broad-spectrum insecticides are the only effective management tool for reducing RGB damage. Certain insecticides from the carbamate, organophosphate and synthetic pyrethroid groups are suitable for controlling RGB. However, they are highly disruptive to natural insect enemies of RGB and applying repeatedly may increase the potential for resistance to those insecticides in other pests.

29 cesar, Rutherglen bug. PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Rutherglen-bug

30 GRDC (2014) Rutherglen bug in sunflower. GRDC Fact sheet, http://ipmguidelinesforgrains.com.au/wp-content/uploads/RGB-FS-FINALweb.pdf

MORE INFORMATION

GRDC (2015) Tip and tactics: Root-Lesion Nematodes. Fact sheet.


Tips and Tactics
ROOT-LESION NEMATODES
WESTERN REGION
FEBRUARY 2015

Root-lesion nematodes (RLN; *Pratylenchus* species) are significant pests that feed on the roots of crop plants and cause yield loss.

KEY POINTS

Nematode management

Root-lesion nemtodes (RLN; *Pratylenchus* spp.) are microscopic, worm-like animals that extract nutrients from plants, causing yield loss. [1]

Root-lesion nematodes are found over 5.74 million hectares (or ~65%) of the cropping area of WA and populations potentially limit yield in at least 40% of these infested paddocks.

The host range of RLN is broad and includes cereals, oilseeds, grain legumes and pastures, as well as many broadleaf and grass weeds.

The main species found in broadacre cropping in WA are *Pratylenchus neglectus*, *P. quasitereoides* (originally described as *P. teres*), *P. thornei* and *P. penetrans*.

Which nematode species are present will affect the suitability of the rotational options.

Barley in the Western Region is considered susceptible to *P. neglectus,* susceptible to *P. quasitereoides* and moderately susceptible to *P. penetrans.* [2]

Table 1: *Resistance of major crop broadacre species to Pratylenchus neglectus, P. quasitereoides and P. penetrans*

Susceptible	Moderately susceptible	Resistant
P. neglectus		
Wheat	Canola	Field peas
Barley	Oats	Lupins
Chickpeas	Durum wheat	Faba beans
		Lentils
		Triticale
		Rye
		Safflower
		Narbon beans
P. quasitereoides **(formerly *P. teres*)**		
Wheat	Canola	Field peas
Barley		Lupins
Oats		
P. penetrans		
Field peas	Barley	
Lupins	Canola	
Chickpeas		
Oats		
Durum wheat		
Wheat		
Triticale		
Faba beans		
Wild oats		
Wild radish		

Souce: Soil Quality Background

1 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd. Fact sheet, http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland

2 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

Root-lesion nematodes use a syringe-like 'stylet' to extract nutrients from the roots of plants (Photo 1). Plant roots are damaged as RLN feed and reproduce inside the plant roots. *Pratylenchus thornei* and *P. neglectus* are the most common RLN species in Australia. These nematodes can be found deep in the soil profile (to 90 cm depth) and in a broad range of soil types, from heavy clays to sandy soils. [3]

New CSIRO research funded by the GRDC is examining how nematodes inflict damage by penetrating the outer layer of wheat roots and restricting their ability to transport water.

Photo 1: *Microscope image of a root-lesion nematode. Notice the syringe-like 'stylet' at the head end, which is used for extracting nutrients from the plant root. This nematode is less than 1 mm long.*

Source: Sean Kelly, DAFWA)

8.1 Symptoms and detection

Root-lesion nematodes are microscopic organisms that occur in soil and plants. The most reliable way to confirm the presence of RLN is to have soil tested in a laboratory.

Signs of nematode infection in roots include dark lesions or poor root structure (Photo 2). The damaged roots are inefficient at taking up water and nutrients—particularly nitrogen, phosphorus and zinc—causing symptoms of nutrient deficiency and wilting in the plant shoots. Intolerant wheat varieties may appear stunted, with yellowing of lower leaves and poor tillering. However, these symptoms may not be present in other susceptible crops such as barley and chickpea. [4]

What is seen in the paddock?

Above-ground symptoms are often indistinct and difficult to identify. The first signs are poor establishment, stunting, poor tillering of cereals, and plants possibly wilting despite moist soil. Nematodes are usually distributed unevenly across a paddock, resulting in irregular crop growth. Sometimes symptoms are confused with nutrient deficiency and they can be exacerbated by a lack of nutrients.

MORE INFORMATION

DAFWA (2014) How to diagnose Root Lesion Nematode. Video.

DAFWA (2014) Crop damaging nematodes found in new area. Media release.

S Collins et al. (2014) Root lesion nematode has a picnic in 2013. GRDC Update Papers.

S Collins et al. (2013) *Pratylenchus teres* WA's home grown Root Lesion Nematode. GRDC Update Papers.

GRDC (2010) Plant Parasitic Nematodes (Southern & Western Region). Fact sheet.

3 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd. Fact sheet, http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland

4 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd. Fact sheet, http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland

Photo 2: *Barley roots with symptoms of Pratylenchus damage including stunting, lack of lateral roots, and browning lesions.*

Source: GRDC

When roots are damaged by RLN (Photo 2), plants are less able to tolerate stresses such as drought or nutrient deficiencies. Depending on the extent of damage and the growing conditions, affected plants may partly recover if the rate of new root growth exceeds the rate at which nematodes damage the roots.

Gaining the full picture requires an examination of what is going on under the ground. Primary and secondary roots of cereals will show a general browning and discoloration and there will be fewer, shorter laterals branching from the main roots.

The root cortex (or outer root layer) may be damaged and it may disintegrate.

Diagnosis is difficult and can be confirmed only with laboratory testing. This is essential if identification is sought to species level as all RLN species cause identical symptoms. The PreDicta B™ soil test (SARDI Diagnostic Services) is a useful tool for several nematode species and is available through accredited agronomists. [5]

RLN and acidic soil

Western Australia's acidic soils could be exacerbating the impact of RLN and limiting crop yields and growers' profitability.

Initial research by DAFWA supported by the GRDC, has found significantly higher RLN populations in barley, lupin and wheat crops grown in low pH soils.

The nematology research group at DAFWA conducted a series of glasshouse trials to test the impact of soil acidity on the multiplication of the main RLN species that impact WA wheat, barley and lupin crops.

The plants were grown in acidic soils (pH 5.1) taken from the same paddock and compared with plants grown in soil that had been treated with lime (pH 6.7).

5 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

Significantly higher final populations of *P. quasitereoides* were recorded for seven of the nine wheat, barley and lupin varieties grown in low pH soil compared with the same varieties grown in the same soil limed to moderate pH.

The same result was recorded in barley for *P. neglectus*.

Diagnostic and management information is available by downloading the free MyCrop app for wheat, barley, canola and lupins. [6]

The life cycle of RLN

Root-lesion nematodes are migratory plant parasitic nematodes, and will migrate freely between roots and soil if the soil is moist. In WA, the life cycle of RLN begins after the opening rains in autumn.

Juvenile and adult nematodes rehydrate, become active and invade plant roots, where they feed and multiply as they move through the root (Figure 1). Individual eggs are laid within the root, from which juvenile nematodes hatch and grow to adults, which in turn lay more eggs. They develop from egg to adult in 40–45 days (~6 weeks) depending on soil temperature and host. There may be 3–5 life cycles within the plant host each season.

As plants and soil dry out in late spring, RLN enter a dehydrated state called anhydrobiosis and can survive high soil temperatures and desiccation over summer. As the nematodes feed and multiply, lesions and/or sections of brown discoloration are formed on the plant root. Other symptoms include reduction in the number and size of lateral roots and root hairs. [7]

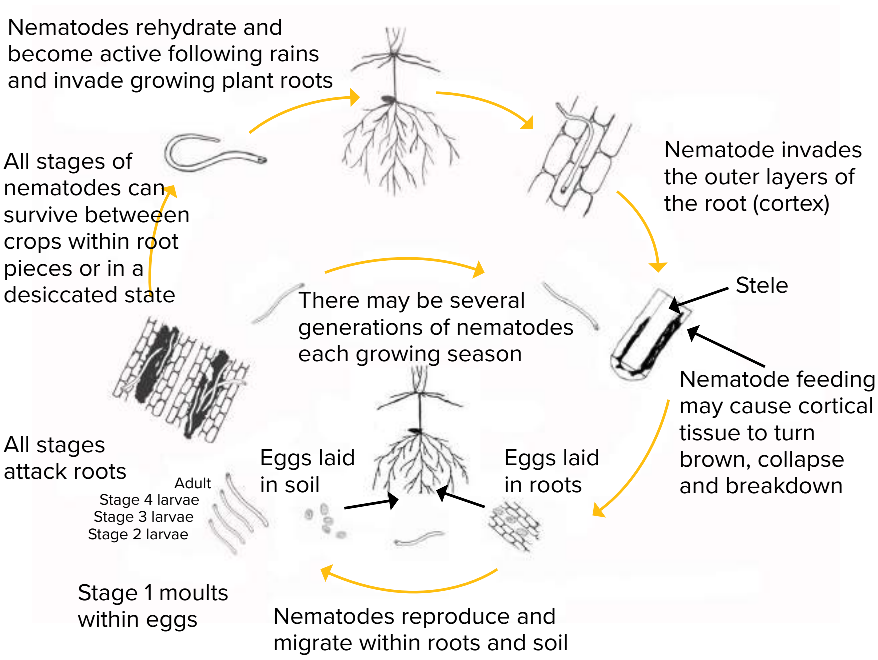


Figure 1: *Disease cycle of root-lesion nematode*

adapted from: GN Agrios (1997) Plant pathology, 5th edn (Academic Press: New York). (Illustration by Kylie Fowler)

6 DAFWA (2015) Soil acidity could increase risk of Root Lesion Nematodes. Media release. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/news/media-releases/soil-acidity-could-increase-risk-root-lesion-nematodes

7 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

P. quasitereoides

P. quasitereoides (originally described as *P. teres*) is unique to WA, and can reach high populations and cause more significant and widespread damage within a crop than *P. neglectus*. Growers need to manage *P. quasitereoides* within their cropping rotations through the use of species which are poor or non-hosts, or use resistant wheat and barley cultivars to limit the multiplication of this pest in the soil. Although *P. quasitereoides* is not as widespread, crops resistant to *P. neglectus* can be highly susceptible to this species, requiring a different suite of rotational crops and cultivars for effective management. It is necessary that in field diagnoses, the species of RLN is correctly identified to enable growers to choose appropriate crop cultivars and species to minimise current and future losses. [8]

Canola has been found to increase *P. quasitereoides* numbers especially if the canola is grown after a long cereal phase.

Economic importance

In WA, all growing regions are affected by RLN (Figure 2) and at least 65% of cropping paddocks are infested with one or more of the *Pratylenchus* species. Populations potentially limit yield in at least 40% of these infested paddocks.

Yield losses in broadacre cropping caused by *P. quasitereoides* or *P. penetrans* are a problem specific to WA. Research is under way to learn more about these species and the rotations that will limit their population below damaging levels in cropping soils. More than one RLN species can be found in the roots of an individual crop, although one species usually dominates.

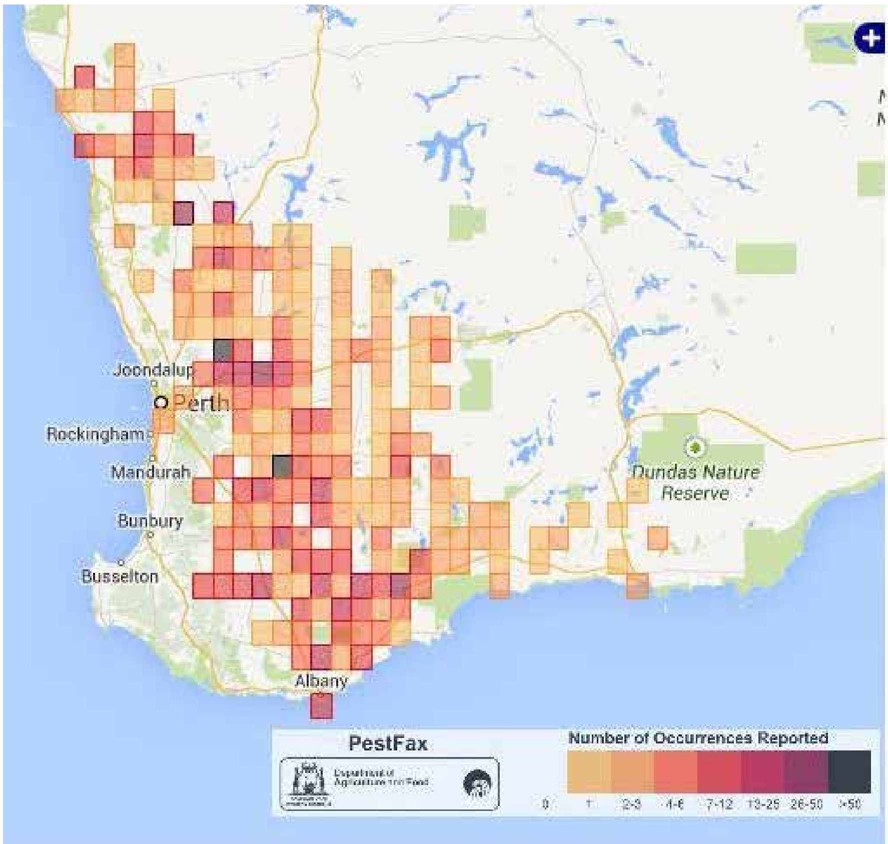


Figure 2: *Positive detection of root-lesion nematodes in Western Australia's broadacre cropping region between 1997 and 2013.*

Source: DAFWA

8 GRDC (2013) *Pratylenchus teres* WA's home grown Root Lesion Nematode. GRDC Update Papers, 12 March 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Pratylenchus-teres-WAs-home-grown-Root-Lesion-Nematode

DAFWA has conducted research for nearly 20 years into the distribution, host range among crop species, variety resistance within crop species, and yield impacts of RLN on crops, including research trials, surveys and Agwest Plant Laboratory diagnostic samples.

During this time, 486 varieties across a wide range of crops have been assessed for resistance to the four main RLN species. [9]

Updated ratings

Recent studies sampling 765 paddocks in the 2014–15 seasons showed at least 50% of infested paddocks had RLN at potentially yield limiting levels. *P. neglectus* was the most frequent RLN, occurring in at least 63% of infested paddocks. P. *quasitereoides* was the next most common RLN at around 26% of infected paddocks surveyed. Cereal yield losses due to RLN are seasonally dependent and are in the order of 5–30%, but can be higher. RLN species *P. neglectus* and *P. quasitereoides* can cause losses of up to 18% in barley crops.

The actual yield loss due to RLN in different barley varieties is not yet quantified, but the impact of different varieties on nematode populations varies. The *P. neglectus* and *P. quasitereoides* nematode resistance scores have been updated since the last sowing guide to reflect WA only based observations. The ratings are based on glasshouse trials 2009–14 for both RLN species plus field trials in 2014–15 for *P. quasitereoides* (3 trials) and 2015 for *P. neglectus* (3 trials). [10]

MORE INFORMATION

DAFWA (2016) 2017 Barley variety sowing guide for Western Australia.

8.2 Varietal resistance or tolerance

Resistance and susceptibility of crops can differ for each RLN species. A resistant crop does not allow RLN to reproduce and increase in number (the opposite is susceptibility). [11] Tolerant varieties grow and yield well when RLN are present.

For example, field peas, lupins and faba beans are resistant to *P. neglectus* but susceptible to *P. penetrans*; barley may be more susceptible to *P. quasitereoides* than to *P. neglectus*; and canola is more susceptible to *P. neglectus* than to *P. thornei.*

Although there is no truly resistant variety of wheat, barley or oats, sufficient variation exists for susceptibility that variety selection in rotations can be a useful tool in managing the impact of RLN.

Pastures vary in their susceptibility to RLN, and under some pasture species, nematode levels could increase and become damaging to subsequent cereals. Pastures should therefore be monitored for RLN, and their place in the rotation should be considered for RLN management.

In glasshouse trials, French and yellow serradella, lotus and sulla varieties were resistant to *P. neglectus*, whereas clovers and medics were more susceptible (Table 2). Serradella has also been used successfully to reduce *P. quasitereoides* to manageable levels in a paddock with a history of high nematode densities.

Intensive cropping of susceptible crops, particularly wheat, will lead to an increase in nematode levels. Rotations are the key to limiting nematode multiplication and reducing future crop damage. [12]

9 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

10 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/sites/gateway/files/Barley%20variety%20sowing%20guide%20for%20Western%20Australia%202017%20web%20version.pdf

11 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd. Fact sheet, http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland

12 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

MORE INFORMATION

To hear Dr Sarah Collins, DAFWA discuss root lesion nematodes at the GRDC Agribusiness Crop Updates in 2014, visit https://www.youtube. com/watch?v=XjtdPy7f0ks

Table 2: *Resistance of pasture species to Pratylenchus neglectus*

Cultivar	Species	Resistance rating
Tanjil lupin	*Lupinus angustifolius*	R
Charano yellow serradella	*Ornithopus compressus*	R
Flamenco sulla	*Hedysarum coronarium*	R
Yelbini yellow serradella	*Ornithopus compressus*	R
Margurita French serradella	*Ornithopus sativus*	R
Cadiz French serradella	*Ornithopus sativus*	MR
Santorini yellow serradella	*Ornithopus compressus*	MR
Erica French serradella	*Ornithopus sativus*	MR
Hykon rose clover	*Trifolium hirtum*	MS
Electra purple clover	*Trifolium purpureum*	MS
Sceptre lucerne	*Medicago sativa*	MS
Mauro biserrula	*Biserrula pelecinus*	S
Casbah biserrula	*Biserrula pelecinus*	S
Caprera crimson clover	*Trifolium incarnatum*	S
Cefalu arrowleaf clover	*Trifolium vesiculosum*	S
Sothis eastern star clover	*Trifolium dasyurum*	S
CFD27 bladder clover	*Trifolium spumosum*	S
2002ESP4 biserrula	*Biserrula pelecinus*	S
Coolamon subterranean clover	*Trifolium subterraneum*	S
Machete wheat	*Triticum aestivum*	S
Nitro Plus Persian clover	*Trifolium resupinatum*	S
Frontier balansa clover	*Trifolium michelianum*	S
Dalkeith subterranean clover	*Trifolium subterraneum*	S
Caliph barrel medic	*Medicago truncatula*	S
Urana subterranean clover	*Trifolium subterraneum*	S
Santiago burr medic	*Medicago polymorpha*	VS
Prima gland clover	*Trifolium glanduliferum*	VS

Note: Information for P. quasitereoides and P. penetrans is based on samples received by Agwest Plant Laboratories for diagnosis, combined with data from preliminary field and glasshouse trials.

Legend: R - Resistant, MR - moderately resistant, MS - moderately susceptible, S - susceptible, VS - very susceptible

Source: GRDC

8.3 Management of nematodes

The most important management tool is using rotations that effectively reduce RLN populations (Figure 3). In heavily infested paddocks, resistant break-crops should be grown for 1 or 2 years to decrease the population. Resistant varieties should be selected for the following years using the WA Crop Variety Guide.

Management of RLN in winter crops includes:

- Observation and monitoring of above- and below-ground symptoms of plant disease followed by diagnosis of the cause(s) of any root disease. Although little can be done during the current cropping season to ameliorate nematode symptoms, the information will be crucial in planning effective rotations of crop species and varieties in following seasons

- Well-managed rotations with resistant or non-host break-crops are vital. To limit RLN populations, avoid consecutive host crops (Table 1)
- Use the DAFWA Crop Variety Guide to choose varieties with high resistance ratings. These will result in fewer nematodes remaining in the soil to infect subsequent crops
- Healthy soils and good nutrition can partly alleviate RLN damage through good crop establishment, and healthier plants may recover more readily from infestation under more suitable growing conditions
- Observe crop roots to monitor development of symptoms
- Weeds can host parasitic nematodes within and between cropping sequences, so choice of pasture species and control of host weed species and crop volunteers is important (Table 1) [13]

Adequate nutrition (especially N, P and Zn) help crops to compensate for the loss of root function caused by RLN, although this does not necessarily lead to lower nematode reproduction. In field trials in areas infested with *P. neglectus*, yield losses for intolerant wheat ranged from 12% to 33% when minimal levels of P were applied, but losses were reduced to only 5% with a high rate of P (50 kg/ha).

Weeds can play an important role in the increase or persistence of nematodes in cropping soils. Thus, poor control of susceptible weeds compromises the use of crop rotations for RLN management.

Wild oats, barley grass, brome grass and wild radish are susceptible to *P. neglectus*.

Several pasture species and varieties are suitable in rotations to reduce RLN when targeted to the species present, but weeds must be managed because they can strongly influence nematode populations at the end of the pasture phase.

Manage volunteer susceptible crop plants, because they can harbour nematodes.

Nematodes cannot move great distances unaided. However, they can be spread through surface water and in soil adhering to vehicles and farm machinery. In uninfested areas, good hygiene should be practised. They can also be spread in dust when they are dehydrated over summer. [14]

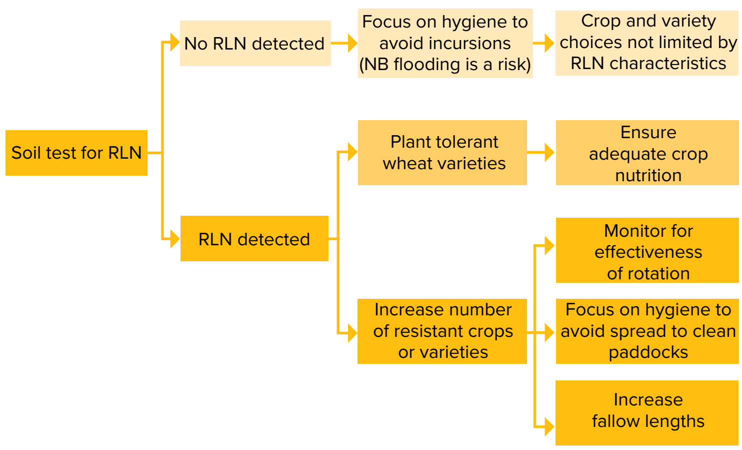


Figure 3: *Root-lesion nematode management flowchart.*

Source: GRDC

13 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

14 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

8.4 Testing for root-lesion nematodes

Two types of test are available for diagnosing nematode infestations:

- Growing season tests can be carried out on affected plants and associated soil. Live nematodes are extracted, counted and identified in the laboratory
- Soil and root testing can be used to define the problem and determine the species of nematode present within and outside of the growing season. Instructions for submitting representative plant and soil samples can be found online at DDLS–Plant pathology services [15]

Growers are advised to check the roots of the host crops if they suspect RLN infestations.

Suspect plants should be dug from the ground with a shovel, not pulled from the ground - this will leave most of the diseased roots behind. The roots must be carefully washed to remove the soil. They can then be inspected for disease by floating them in a white tray containing water, and looking for symptoms of nematode damage.

If evidence of infestation in the roots is observed, then a laboratory analysis or a PreDicta B™ test can be used to determine species and density.

The DNA-based soil testing service PreDicta B™, provided by SARDI Diagnostic Services, can detect *P. neglectus, P. thornei* and *P. quasitereoides*. [16]

However, this test does not identify *P. quasitereoides* (common in barley) and *P. penetrans*. Growers are advised to contact their local DAFWA office for advice.

Plant pathology services can assist with diagnosis. To obtain submission forms and full sampling instructions contact your local DAFWA office or find information online on the DAFWA website at DDLS–Plant pathology services or you can contact the labs by phone on +61 (0)8 9368 3721. [17]

15 DAFWA (2016) Diagnosing root lesion nematode in cereals. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2166

16 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

17 DAFWA (2016) Diagnosing root lesion nematode in cereals. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2166

Diseases

Barley diseases cause an estimated average annual loss of AU$252 million, or $66.49 per hectare, to the Australian barley industry. In the decade to 2009, this loss represented 19.5% of the average annual value of the barley crop. [1]

In WA, powdery mildew, net blotch (spot type), net blotch (net type), Rhizoctonia and *Pratylenchus neglectus* nematode are the main diseases affecting barley (Table 1). They can all have serious impacts on grain yield and quality. [2]

Diseases occur when a susceptible host is exposed to a virulent pathogen under favourable environmental conditions. Control is best achieved by knowing the pathogens involved and manipulating the interacting factors. Little can be done to modify the environment, but growers can minimise the risk of diseases by sowing resistant varieties and adopting management practices to reduce inoculum levels. Rotate barley crops with non-hosts such as legumes, avoid sowing barley on barley, and maintain clean fallows. Sowing out of season favours disease development and can build up inoculum early in the season. [3]

Table 1: *Five major diseases by potential loss in WA*

Disease	$/ha	$ million
Powdery mildew	71.36	72
Net blotch, spot type	43.12	43
Net blotch, net type	41.15	42
Rhizoctonia barepatch	33.78	34
Pratylenchus neglectus	28.42	29

Source: GRDC

Diseases can severely affect yield and quality in barley. In some cases, diseases are controlled through simple cultural practices and good farm hygiene. One of the major practices used in the control of diseases is crop rotation.

To minimise the effect of diseases:

- Use resistant or partially resistant varieties
- Use disease-free seed
- Use fungicidal seed treatments to kill fungi carried on the seed coat or in the seed
- Plan an in-crop fungicide regime
- Conduct in-crop disease audits to determine the severity of the disease and use as a tool to determine which crop is grown in which paddock the following year
- Conduct over summer disease audits to determine the severity of the disease (e.g. crown rot, cereal cyst nematode and Rhizoctonia bare patch) and assist in planning for the following year
- Send plant or stubble samples away for analysis to determine the pathogen or strain, or the severity of the disease
- Minimise the growth of self-sown cereals over summer that may act as a green bridge.
- Rotate crops [4]

MORE INFORMATION

GRDC (2009) Current and potential costs from diseases of barley in Australia.

GRDC (2010) Green bridge control is integral to pest and disease management. Fact Sheet.

1 G Murray, JP Brennan (2009) The current and potential costs from diseases of barley in Australia. GRDC, https://grdc.com.au/resources-and-publications/all-publications/publications/2009/11/the-current-and-potential-costs-from-diseases-of-barley-in-australia

2 UNE Sustainable Grains Production course notes.

3 DAF Qld (2012) Barley diseases. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/diseases

4 DAF Qld (2012) Wheat—diseases, physiological disorders and frost. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

Some diseases are easily identifiable visually and others require stubble or soil tests to identify inoculum types and infestations in paddocks. Selecting suitable varieties as part of your rotation is essential to combat yield and/or quality losses and even disease epidemics on-farm.

9.1 Causes of cereal diseases

Cereal diseases are caused by fungi, viruses, bacteria and nematodes.

These pathogens (disease-causing organisms) often reduce grain yields by damaging green leaves, preventing them from producing the sugars and proteins needed for growth. In other cases, they block or damage the plant's internal transport mechanisms, reducing the movement of water and sugars through the plant. Yields are also reduced when the pathogen diverts the plant's energy into reproducing more of the pathogen at the expense of plant growth or grain formation.

Fungi

Fungi come in a diverse variety of forms. They spread by producing one or more types of spores, which may be carried by wind, through raindrop splashes or, in the case of smuts, by mechanical movement and mixing during harvest. Some fungi survive as spores in the soil, on seed or on plant debris. Others survive as fine threads of growth inside plant debris or seed and produce fresh spores in the following season. Spores are sometimes produced inside small fruiting bodies on infected plant tissue or stubble. Some diseases such as rust require continuous green host plants to survive from one season to the next.

Viruses

Viruses are invisible to the eye and even through a conventional microscope. Unlike other pathogens, viruses are totally dependent on the host for growth and multiplication. They cannot survive outside the plant, except in an insect or other animal that transmits the disease. They often damage plants by blocking its transport mechanisms. Barley yellow dwarf virus (BYDV) is a virus that affects all cereals.

Bacteria

Bacteria differ from fungi in that they do not form fine threads of growth, but instead multiply rapidly by continually dividing. They grow best under damp conditions and do not survive as well as fungi under dry conditions.

Nematodes

The main species found in broadacre cropping in WA are *Pratylenchus neglectus*, *P. quasitereoides* (originally described as *P. teres*), *P. thornei* and *P. penetrans*.

When roots are damaged by RLN, the plants become less efficient at taking up water and nutrients, and less able to tolerate stresses such as drought or nutrient deficiencies. Depending on the extent of damage and the growing conditions, affected plants may partly recover if the rate of new root growth exceeds the rate at which nematodes damage the roots. [5]

See Section 8: Nematodes.

MORE INFORMATION

Section 8: Nematode management

DAFWA (2016) Diagnosing root lesion nematode in cereals.

9.2 The disease triangle

Plant pathologists talk about the occurrence of disease in terms of the '*disease triangle*' (Figure 1)—an interaction of host, pathogen and environment. Alteration to any of these components of the disease triangle will influence the level of disease.

5 GRDC (2015) Tips and Tactics: Root-Lesion Nematodes, Western Region, Fact sheet, http://www.grdc.com.au/TT-RootLesionNematodes

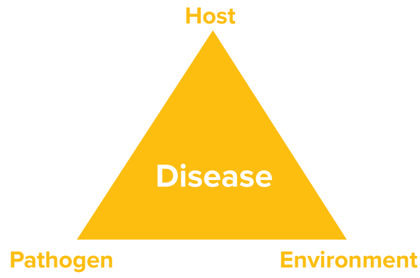


Figure 1: *The disease triangle is an interaction of host, pathogen and environment.*

For disease to occur, there must be a susceptible host and a virulent pathogen, and the environment must be favourable. Some important examples of interactions of environmental conditions with diseases of grain crops are as follows:

- Low temperatures reduce plant vigour. Seedlings become more susceptible to *Pythium*, *Rhizoctonia,* nematodes and other root and damping-off pathogens if they are emerging in soils at below their optimum temperature
- Pathogens have different optimum temperature ranges. For example, hatching in nematodes tends to occur over narrow soil temperature ranges, 10–25°C and optimal at 20°C, whereas take-all fungus *Gaeumannomyces graminis* var. *tritici* is more competitive with the soil microflora in cooler soils. This can lead to diseases being more prevalent in certain seasons or in different areas, such as wheat stem rust in warmer areas and stripe rust in cooler areas
- Fungi such as *Pythium* and *Phytophthora* that have swimming spores require high levels of soil moisture in order to infect plants; hence, they are most severe in wet soils
- Foliar fungal pathogens such as rusts require free water on leaves for infection. The rate at which most leaf diseases progress in the crop depends on the frequency and duration of rain or dew periods
- Diseases that attack the roots or stem bases, such as crown rot, reduce the ability of plants to move water and nutrients into the developing grain. These diseases generally have more severe symptoms and larger effects on yield if plants are subject to water stress [6]

Information on the main diseases affecting barley, including their control, is presented in Table 2.

6 UNE Sustainable Grains Production course notes.

Table 2: *Barley disease guide*

Disease	Organism	Symptoms	Occurrence	Inoculum source	Control
Foliar					
Scald	*Rhynchosporium secalis*	Water-soaked areas on leaves. Lesions appear grey-green then bleached with brown margins	Years with frequent rain and early sown crops	Residues of barley and barley grass. Can be seed-borne. Spores spread by rain-splash	Resistant varieties, clean seed, managing barley and barley grass debris. Seed and foliar fungicides
Net blotch spot form	*Pyrenophora teres f. maculata*	Dark brown spots to 10 mm, with yellow margins	Infection from stubble especially in wet autumn conditions	Barley and barley grass stubble, also airborne spores from infected crops	Control barley grass and manage barley stubble. Avoid very susceptible varieties. Foliar fungicides
Net blotch net form	*Pyrenophora teres f. teres*	Small brown spots that develop into dark brown streaks on leaf blades that have net like appearance	Spores can be produced for >2 years on stubble. Moist conditions, temperatures in the 15–25°C range	Survives on infected barley and barley grass residues. Wind borne spores	Resistant varieties, crop rotation and stubble management
Powdery mildew	*Blumeria graminis f.sp. hordei*	White powdery spores on upper leaf surfaces, underside of leaves turn yellow to brown	Favoured by high humidity and temperature of 15–22°C. Worse in high-fertility paddocks and early sown crops	Volunteer barley, barley grass and crop residue. Airborne spores	Resistant varieties. Seed and foliar fungicides
Leaf rust	*Puccinia hordei*	Small circular orange pustules on upper leaf surface	Moist conditions with temperatures in the range 15–22°C	Living plant hosts including barley and barley grass	Use resistant varieties and control volunteer barley and barley grass over summer–autumn
Stem rust	*Puccinia graminis*	Large red-brown pustules. Rupture of leaf and stem surface	Infection requires temperatures in the 15–30°C range and moist conditions	Living plant hosts including volunteer cereals (wheat, barley, triticale and rye)	Use resistant varieties and control volunteer cereals over summer–autumn
BGSR (barley grass stripe rust)	*Puccinia striiformis*	Yellow powdery pustules in stripes on the leaves	Can develop throughout the growing season	Barley grass and susceptible barley varieties	Avoid susceptible varieties
BYDV	*Barley yellow dwarf virus*	Yellow stripes between leaf veins, some leaves red. Sterile heads and dwarfing plants	Virus is transmitted by aphids	Hosts include all cereals and many grasses	Resistant varieties. Chemical control of aphids may be suitable for high value crops
Wirrega blotch	*Drechslera wirreganensis*	Brown blotches often with hole in centre	Minor occurrence	Range of grass weeds and cereal stubble	Crop rotation. Avoid growing susceptible varieties, control grass weeds
Ringspot	*Drechslera campanulata*	Small brown rimmed spots on leaves	Common and widespread in southern Australia	Wide range of cereals and grass weeds. Barley seed in crop residue infected with fungus	Crop rotation and weed control
Halo spot	*Pseudoseptoria stomaticola*	Small white-brown lesions.	Cool, moist conditions	Residues of barley and grasses. Rain-splash	Disease is not of economic importance

Disease	Organism	Symptoms	Occurrence	Inoculum source	Control
Grain					
Covered smut	*Ustilago segetum* var. *hordei*	Dark, compacted heads, grain replaced by smut balls	Spores germinate in infected grain when temperatures are 14–25°C	Infected seed	Use disease-free seed, resistant varieties, seed treatments
Loose smut	*Ustilago tritici*	Dark brown powdery spores replace grain	Moist conditions at flowering and when temperatures are 16–22°C	Infected seed	Use disease-free seed and seed treatments. Avoid susceptible varieties
Root/crown					
Crown rot	*Fusarium pseudograminearum, F. culmorum*	'Whiteheads' or deadheads most obvious after flowering, pink discoloration under leaf sheaths	Most common on heavy or poorly drained soils Favoured by moist, humid conditions with temperatures 15–30°C	Survives in infected stubble residue for up to 2 years. Hosts include wheat, barley, triticale and some grasses	Crop rotation, stubble removal, cultivation
Pythium root rot (Damping off)	*Pythium* spp.	Stunted seedlings, reduced tillering, pale stunted or stubby roots with light brown tips	Favoured by wet conditions. Increased risk where high rainfall occurs after sowing	Spores survive in soil or plant debris for up to 5 years	Avoid deep sowing into cold wet soils, especially when direct drilling. Ensure good nutrient levels
Common root rot	*Bipolaris sorokiniana*	Brown discoloration of roots, sub-crown internode and crown. Plant stunting, brown spots on leaves and reduced tillers	Scattered through crop	Wheat, barley, triticale and rye	Crop rotation
Cereal cyst nematode (CCN)	*Heterodera avenae*	Yellow, stunted plants. Knotted roots	Light soils and well-structured clays where cereals are commonly grown	Present in most soils in the southern region	Resistant varieties, break from susceptible cereals and grasses, particularly wild oats
Root lesion nematode (RLN)	*Pratylenchus thornei. P. neglectus*	Reduced tillering, ill thrift; lesions on roots, lack of branching of root system	Favoured by cereals in rotation with chickpeas, medic and vetch	Survives as dormant nematodes in the soil	Crop rotation using resistant crops and resistant varieties
Take-all	*Gaeumannomyces graminis* var. *tritici* (*Ggt*)	Stunted or yellowing plants, 'whiteheads' at heading	Fungus thrives under warm, damp conditions	Fungus survives over summer in crowns and roots of wheat, barley and grass plants	Crop rotations, at least one year free of hosts (cereals and grasses, especially barley grass). Fungicide applied to seed or fertiliser

Table has been developed from information in the publications: H Wallwork (Ed) (2000) Cereal root and crown diseases (GRDC, SARDI) and H Wallwork (Ed) (2000) Cereal leaf and stem diseases (GRDC, SARDI).

9.3 Variety response

Most varieties have been stable in their adult disease rating since 2013, except where there has been a pathotype change resulting in a loss of a major resistance gene (e.g. Rph3 virulence in barley leaf rust). Disease status for varieties includes:

- Scald—risk likely to increase if significant areas of Granger⊕ barley are sown
- Net type net blotch—risk not expected to change with the adoption of newer varieties
- Spot type net blotch—risk expected to continue to increase with greater plantings of Hindmarsh⊕ and La Trobe⊕

- Powdery mildew—overall risk is expected to decline until new pathotypes become dominant
- Barley leaf rust—growing varieties with adult plant resistance (APR) can reduce the risk, but fungicide spraying may still be required
- Barley yellow dwarf—risk expected to increase with increased plantings of Hindmarsh⌽ and La Trobe⌽ [7]

Barley varieties carry varying tolerance and resistance to diseases (Table 3).

Table 3: *Barley variety disease ratings*

	Leaf scald	Net blotch Spot form	Net blotch Net form	Powdery mildew	Leaf rust	BYDV	CCN resis.	RLN resistance P. neglectus	RLN resistance P. thornei	BGSR
Malting barley										
Baudin⌽	S-VS	MS-S	MR-MS#	VS	VS	MR	S	MR	–	R
Buloke⌽	MS	S	MR	MR	S-VS	MR-MS	S	MR-MS	MR-MS	R
Commander⌽	S	MSS	MS-S	MR-MS#	S	MR-MS	R	MR-MS	MR-MS	R
Fairview	S-VS	S	S	R-MR	MRp	MR	–	–	–	R
Gairdner	S-VS	S	MR-MS	S	S	S	S	MR-MS	MS	R
Granger⌽	S	S-VS	MS	MR	MR#	MR-MS	R	MR	MR	R
Navigator	MR-MS	MR-MS	MR#	R	VS	S	R	MR-MS	MR-MS	R
Scope CL⌽	MS-S	MSS	MR	R#	S-VS	MR	S	MR-MS	MR-MS	R
Westminster	R#	S	MS-S	R	MR-MS	MR-MS	–	MR-MS	MR-MSp	R
Wimmera⌽	MS-S	S	MS-S	S	MR#	MR-MS	S	MR-MS	MR-MS	MR
Feed barley										
Capstan	S	MS	MS-S	MR	MR-MS	S	R	–	–	MR-MS
Fathom⌽	MR#	MR	MS	MR-MS	MS-S	MR-MS	R	MR-MS	MR-MS	R
Fleet⌽	MS-S	MR	MR-MS#	MR	MS-S	MR-MS	R	MR-MS	MR-MS	R
Hindmarsh⌽	S-VS	S-VS	MR	MR-MS#	MS-S	S	R	MR-MS	MR-MS	R
Keel	MS	MR	MR#	MS	VS	S	R	–	–	MS
Oxford⌽	MS-S#	S	MS	R	MR	MS	S	MR	MR-MS	R
Barley under malt evaluation										
Compass⌽	MS#	MS-S	MR#	MR#	VS	MR	R	MR	MR	R
Flinders⌽	S	S	S	R-MR	MS	MR-MS	S	MR-MS	MR	R
La Trobe⌽	VS	S	MR	MR-MS#	MS-S	S	R	MR	MR	R
Skipper⌽	S	MR-MS	MR	MR	SVS	MR	R	MR-MS	MR-MS	R
SY Rattler	MS#	SVS	MR#	R	MR-MS	S	–	RMR	MR-MS	R

BGSR, Barley grass stripe rust. Varieties marked may be more susceptible if alternative strains are present; p, rating provisional (treat with caution); R, resistant; R-MR, resistant to moderately resistant; MR, moderately resistant; MR-MS, moderately resistant to moderately susceptible; MS, moderately susceptible; MS-S, moderately susceptible to susceptible; S, susceptible; S-VS, susceptible to very susceptible; VS, very susceptible

7 S Gupta and B Paynter et al. (2015) Change in adult foliar disease resistance profiles of barley varieties grown in Western Australia from 2013 to 2015. 2015 Agribusiness Crop Updates, Perth, 24–25 Feb 2015. http://www.giwa.org.au/2015-crop-updates

9.4 Environmental factors

9.4.1 Cereal disease after drought

Drought reduces the breakdown of plant residues. This means inoculum of some diseases such as crown rot, net blotch and leaf scald, does not decrease as quickly as expected, and will carry over for more than one growing season. The expected benefits of crop rotation may not occur or may be limited. Conversely, bacterial numbers decline in dry soil. Some bacteria are important antagonists of soilborne fungal diseases such as common root rot, and these diseases can be more severe after drought. [8]

9.4.2 Cereal disease after significant rain events

For disease to occur, the pathogen must have virulence to the particular variety, inoculum must be available and easily transported, and there must be favourable conditions for infection and disease development.

The legacy of floods and rain includes transport of inoculum (crown rot, nematodes, leaf spots through movement of infected stubble and soil), development of sexual stages (leaf spots, head blights), survival of volunteers (unharvested material and self-sown plants in double-crop situations), and weather-damaged seed. [9]

9.5 Management options

Management options for disease control include elimination of volunteers, ideally having a 4-week period that is totally host-free, crop rotation with non-hosts, growing resistant varieties, reduction of stubble, and the use of fungicides.

Fungicides are far more effective as protectants than eradicants, so are best applied prior to, or very soon after, infection. Systemic fungicides work within the sprayed leaf, providing 3–5 weeks of protection. Leaves produced after this spraying are not protected. Spray to protect the upper three or four leaves, which are the most important because they contribute to grainfill. In general, rusts are easier to control than leaf spots. Fungicides do not improve yield potential; they can only protect the existing yield potential.

The application of fungicides is an economic decision, and in many cases, a higher application rate can give a better economic return through greater yield and higher grain quality. [10]

9.5.1 Strategies

The incidence and severity of disease will depend on the environment, but with plentiful inoculum present, even in a season with average weather, disease risks will be significant.

Strategies include:

- using the best available seed
- identifying your risks
- formulating management strategies based on perceived risk
- monitoring crops regularly
- timely intervention with fungicides [11]

MORE INFORMATION

- NSW DPI (2006) Cereal diseases after drought
- GRDC (2016) Yield response to fungicide control of barley. GRDC Update Paper.
- GRDC (2016) Yield response to fungicide control of barley spot type net blotch in Western Australia. GRDC Research Update.
- DAFWA (2016) Managing barley leaf diseases in Western Australia.
- DAFWA (2015) Diagnosing barley leaf rust.
- The Rust Bust Western Australia
- DAFWA (2008) Managing barley leaf diseases. Farmnote 288.
- DAFWA (2016) Registered foliar fungicides for cereals in Western Australia.
- GRDC (2016) New cereal rusts in WA and implications for management. GRDC Research Update.
- GRDC (2014) Barley leaf rust in Western Australia.
- CropPro (2014) Foliar diseases of barley.

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8 G Murray, T Hind-Lanoiselet, K Moore, S Simpfendorfer, J Edwards (2006) Cereal diseases after drought. Primefacts. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/123718/crop-diseases-after-drought.pdf

9 DAF Qld (2013) Winter cereals pathology. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/winter-cereals-pathology

10 DAF Qld (2013) Winter cereals pathology. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/winter-cereals-pathology

11 DAF Qld (2013) Winter cereals pathology. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/winter-cereals-pathology

FAQ

9.6 Rusts

Rusts are important diseases of barley and can cause severe crop damage in susceptible varieties when conditions are conducive. Rusts can be effectively controlled with resistant varieties and cultural management methods such as controlling volunteers between seasons and the use of foliar fungicides.

Four rusts can attack barley:

- Leaf rust (caused by *Puccinia hordei*) is the most common
- Stem rust (caused by *Puccinia graminis*) is less common but can cause severe crop loss in favourable years
- Barley grass stripe rust (causal agent currently unnamed) is common and infects some susceptible varieties
- Barley stripe rust (caused by *Puccinia striiformis*) is an exotic disease

Leaf rust occurs in susceptible varieties in most years, especially in high-rainfall regions. Early infections (June–July) can result in yield losses of up to 20%. Stem rust is potentially the most devastating disease of the rusts and is able to cause complete crop loss; however, suitable conditions for a severe outbreak are rare. Barley grass stripe rust can cause yield loss in susceptible varieties when conditions are favourable although this is rare in WA. The exotic pathogen barley stripe rust will cause severe losses in most varieties if it is introduced to Australia. [12]

Rust diseases can be significantly reduced by removing the green bridge. This should be done well before the new crop is sown, allowing time for any herbicide to work and for the fungus to stop producing spores.

Wherever possible, varieties that are resistant should be sown (i.e. MR, moderately resistant and above).

Rust fungi continually change, producing new pathotypes. These pathotypes are detected when disease is found on a previously resistant variety. Even if a resistant variety has been sown, the crop should be regularly monitored for foliar diseases.

Monitoring should start no later than Zadoks growth stage GS32, the second node stage on the main stem, and continue to at least GS39, the flag-leaf stage. This is because the flag to minus 1-leaf and the two leaves below it are the main factories contributing to yield and quality. It is most important to protect these leaves from diseases. [13]

Key points to reduce the risk of rusts in cereals

- Destroy volunteer cereal plants by March, because they can provide a green bridge for rust carryover
- Community effort is required to eradicate volunteers from roadsides, railway lines, bridges, paddocks and around silos
- Growing resistant varieties is an economical and environmentally friendly means of disease reduction
- Seed or fertiliser treatment can control stripe rust up to four weeks after sowing and suppress it thereafter
- During the growing season, active crop monitoring is important for early detection of diseases
- Correct disease identification is crucial
- When deciding whether a fungicide spray is needed, consider crop stage and potential yield loss
- Select a recommended and cost-effective fungicide

12 CropPro (2014) Foliar diseases of barley. GRDC/State Government Victoria, http://www.croppro.com.au/crop_disease_manual/ch02s04.php

13 DAF Qld (2012) Wheat—diseases, physiological disorders and frost. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

MORE INFORMATION

Barley Variety sowing guide https://www.agric.wa.gov.au/barley/2017-barley-variety-sowing-guide-western-australia

GRDC (2012) Adult plant resistance. Fact Sheet.

GRDC (2008) Stripe rust—prevention is generally best. GRDC Update Paper.

- For effective coverage, the use of the right spray equipment and nozzles is important
- Avoid repeated use of fungicides with the same active ingredient in the same season
- Check for withholding periods before grazing and harvesting a crop that has received any fungicide application

Adult plant resistance (APR) is a useful trait to consider in variety selection, especially for rust resistance. Understanding how it works can make fungicide application decisions easier. APR to cereal fungal diseases provides protection in a crop's post-seedling stages (typically between tillering and booting, GS20–GS49).

Seedling resistance, by comparison, is effective at all growth stages. APR can complement a fungicide strategy by protecting from rust those parts of the plant most responsible for yield. When selecting a variety, choose one rated at least MR–MS (moderately resistant–moderately susceptible, the minimum disease resistance standard). In high-risk regions, varieties rated at least MR are recommended.

Where the more susceptible varieties are used, ensure a suitable fungicide strategy is in place, with the right chemicals available at short notice. Fungicides are better at protecting than curing. Fungicide applications on badly infected crops provide poorer control and do not restore lost green leaf area. [14]

9.6.1 What to look for

Barley leaf rust

Pustules of leaf rust are small and circular, producing a mass of orange-brown powdery spores predominantly on the upper leaf surfaces (Photo 1). Later in the season, pustules also develop on leaf sheaths. The pustules easily rub off on a finger. As the crop matures the pustules turn dark and produce black spores embedded in the old plant tissues. Leaf and stem rust may be confused but are distinguished by their colour and size, leaf rust being lighter coloured, smaller and rounder than stem rust.

Photo 1: *Leaf rust symptoms on barley leaf.*

Source: GRDC

14 GRDC (2012) Adult plant resistance. Northern, Western and Southern Regions. GRDC Fact Sheet, , http://www.grdc.com.au/GRDC-FS-AdultPlantResistance

Barley stem rust

The large pustules are oval to elongated, and are often surrounded by a characteristic torn margin (Photo 2). The pustules are full of reddish brown spores, which fall away easily. They can occur on stems, leaf surfaces, the leaf sheaths and heads. As a plant matures, the pustules produce black spores that do not dislodge.

Photo 2: *Stem rust symptoms on barley.*

Source: GRDC

Barley grass stripe rust

Symptoms are very similar to stripe rust in wheat. Bright yellow-orange spores form pustules, which occur in stripes along the leaves (Photo 3). In young leaves, the pustules tend to be scattered across the leaf. Spores rub off easily onto a finger. Barley grass stripe rust and barley stripe rust have the same symptoms. [15]

Photo 3: *Barley grass stripe rust symptoms on barley.*

Source: GRDC

15 CropPro (2014) Foliar diseases of barley. GRDC/Government of Victoria, http://www.croppro.com.au/crop_disease_manual/ch02s04.php

9.6.2 Disease cycle

Barley leaf rust

Leaf rust requires a green host plant to survive the summer, so disease risk is highest when a green bridge allows the fungus to survive into the new season. Leaf rust can occur throughout the season and develops rapidly in moist conditions when temperatures are between 15–22°C. [16]

Stem rust of barley

Stem rust survives the summer on volunteer wheat, barley, triticale and grasses, including barley grass. Spores are spread from these hosts to the new crop by the wind, with high humidity and heavy dew favour its development. It is most rapid at temperatures near 20°C and is markedly reduced by temperatures ≤15°C and ≥40°C. Wet summer weather causes growth of self-sown wheat and other hosts of stem rust. These plants can become heavily infected with stem rust in autumn and be a source of rust for the new season's barley or wheat crop. If these conditions are followed by a mild winter and a warm wet spring, the chances of a stem rust epidemic are high.

Barley grass stripe rust

Barley grass stripe rust survives over summer on self-sown barley and barley grass. Little is known about the conditions that favour its infection. [17]

9.6.3 Management of barley rusts

Resistant varieties

Barley rust is aggressive, difficult to control and can be a recurring problem in crops in the southern high rainfall zones of WA. Planting resistant varieties is one of the easiest ways to help control leaf rust. GRDC-funded research has led to the development of several resistant barley varieties, such as Fleet⁽ᴾ⁾. Oxford⁽ᴾ⁾, Granger⁽ᴾ⁾ and Westminster also have good levels of leaf rust resistance.

See Table 3 for more information.

Cultural practices

Crop rotation with a non-host crop in the previous year will minimise initial inoculum levels for the current season's crop. To further reduce disease pressure, avoid sowing the current season's crop in paddocks adjoining those with barley stubble from the previous season. Cultural practices such as incorporating the residue into the soil or removing it completely (for example, by burning) will reduce the abundance of the pathogen and the disease pressure. Stubble may be reduced by baling and grazing; however, these methods only result in a small reduction in the disease pressure. Stubble reduction must be balanced against the increased risk of soil erosion by wind or water.

Barley leaf rust survives on barley volunteers. A green bridge of self-sown barley leading into the cropping season provides host material. Removing this green bridge as early as practicable before seeding will greatly reduce the risk of early crop infection. [18]

Seed treatment

New active ingredient fluxapyroxad (product Systiva®) is now registered as a seed dressing for the control of barley leaf rust. No in-furrow or seed dressing fungicides are currently registered for barley stem rust. [19]

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16 DAFWA (2015) Diagnosing barley leaf rust. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2543

17 CropPro (2014) Foliar diseases of barley. GRDC/Government of Victoria, http://www.croppro.com.au/crop_disease_manual/ch02s04.php

18 DAFWA (2016) Managing barley leaf diseases in Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/343

19 DAFWA (2016) Seed dressing and in-furrow fungicides for cereals in Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1794

Fungicides

Apply fungicide spray if disease threatens well grown crops. Where an early outbreak of leaf rust in barley occurs, the initial spray should be applied at the onset of the disease and followed by a second application three to four weeks later. Early foliar fungicide sprays are more effective than seed dressing or in-furrow fungicide application for control of early infections of barley leaf rust. [20]

Changes in the barley leaf rust pathogen

A new pathotype of the barley leaf rust pathogen *Puccinia hordei* was detected in WA in 2013 from samples collected in the southern region (Boxwood Hill, Chillinup, Esperance, Kamballup and South Stirling).

The leaf rust responses of most of barley varieties grown in WA have not changed due to this pathotype. The concern was that it may have reduced leaf rust resistance in varieties known to carry resistance gene Rph3, in Oxford⁽ᵖ⁾, Granger⁽ᵖ⁾, Bass⁽ᵖ⁾ and Compass⁽ᵖ⁾. Fortunately, two of these varieties (Granger⁽ᵖ⁾, Oxford⁽ᵖ⁾) also carry the APR gene Rph20, and they remain resistant. Bass⁽ᵖ⁾ is also considered to carry Rph20 in addition to Rph3, but its response appears to have shifted more towards susceptibility and it is now rated as being Moderately Susceptible.

It is important to monitor crops of vulnerable varieties for leaf rust and send samples for pathotype analysis to the Australian Rust Survey. This service is free and is funded by the grower levy paid to the Grains Research and Development Corporation. [21]

9.7 Barley scald

Barley scald is a stubble- and seed-borne fungal foliar disease which occurs more frequently in high rainfall cooler areas. It can cause grain yield losses up to 45% and reduce grain quality.

The optimum temperature for both spore production and infection is 15–20°C. Rain aids the spread of disease and the most rapid increase in disease is observed in early spring when the temperature and moisture conditions are ideal.

Early sown crops develop higher levels of scald. Early sown crops may be exposed to the heaviest release of spores from infected residues. The disease can develop in the upper leaves of the plant when conditions favour spread of disease.

Disease is more severe at higher levels of nitrogen supply. [22]

What to look for

The disease causes scald-like lesions of the leaf blades and sheaths. At first, the lesions are water-soaked, but they change from grey-green to a final straw colour with a distinctive brown margin, and are oval to irregular in shape (Photo 4). In severe infections, the disease may virtually cause defoliation by coalescing of the lesions (Photo 5). The size and colour of the lesions and their presence on the older leaves distinguishes scald from numerous other lesions, often non-parasitic, which may be seen on barley after heading.

20 GRDC (2014) Barley leaf rust in Western Australia. GRDC Media Centre, https://grdc.com.au/Media-Centre/Hot-Topics/Barley-leaf-rust-in-Western-Australia

21 R Park (2016) New cereal rusts in Western Australia and implications for management. GRDC Grains Research Updates, 29 Feb–01 Mar 2016, http://www.giwa.org.au/2016researchupdates

22 DAFWA (2015) Diagnosing barley scald. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2553

Photo 4: *Barley scald. Early water-soaked, grey-green symptoms compared with later straw-coloured lesions with a distinctive brown margin.*

Source: GRDC

Photo 5: *Severe barley scald. Note the scald-like lesions can coalesce and cause complete leaf loss.*

Disease cycle

Rhynchosporium secalis survives over summer on stubble of infected plants. During the growing season and in wet weather, spores are produced on the stubble and are dispersed by rain splash into the new season's crop, where they start the primary infection (Figure 2). Scald is usually first observed in isolated patches in the crop when plants are tillering. Further spread is caused by splash dispersal of spores, which is more rapid in the warmer months. By the end of the growing season scald is usually evenly distributed within the crop with distinct hotspots. The disease is more severe in seasons of above average rainfall, particularly during spring.

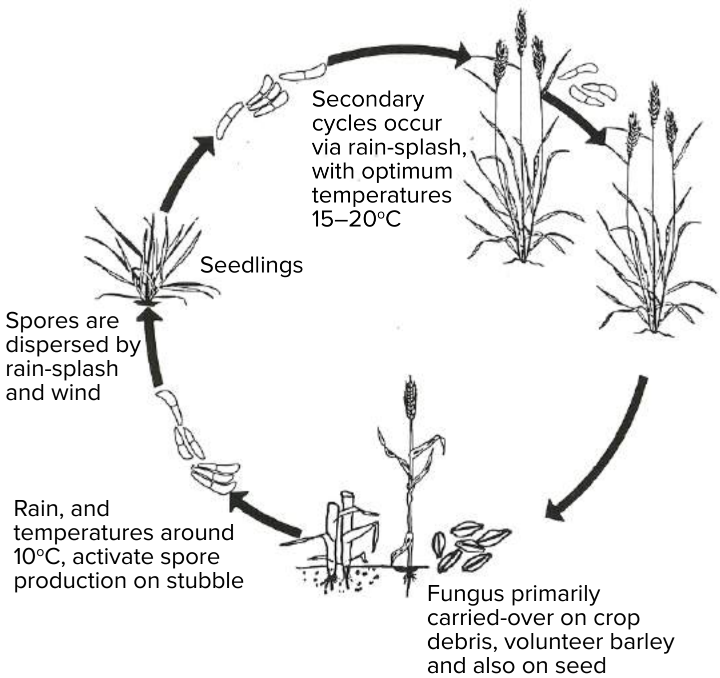

Figure 2: *Disease cycle of barley scald.*

Hosts

Scald can be seed-borne, infect barley grass and survive on volunteers. These sources are not as important as infected stubble but can be an inoculum source for barley crops, especially during seasons with favourable climatic conditions.

Management

Cultural practices

Reducing infected stubble and barley grass by grazing, burning or cultivation decreases the carry-over of the fungus between crops. However, these practices will not eliminate the disease altogether because scald will survive on any remaining residue. Rotations involving consecutive barley crops should be avoided, with up to two years required between crops for residue to break down sufficiently. Scald is also worse in early-sown crops, so avoiding early sowing of susceptible varieties, especially in high-rainfall areas, will reduce the loss caused by scald

Resistant varieties

Cultivation of resistant varieties gives the best long-term control of the disease. The risk of grain yield and quality loss is also greatly reduced by avoiding growing susceptible and very susceptible varieties. However, the fungus is pathogenically variable, with resistance being broken down over time.

Fungicides

A range of foliar fungicides is available that will provide suppression of scald. Experiments conducted during 2010 and 2011 showed the best suppression of scald was achieved when foliar fungicides were applied between the beginning of stem elongation (GS31) and flag leaf emergence (GS39). A single application of foliar fungicide may be insufficient to eliminate grain yield and quality loss. In some cases, a two-application strategy at both GS31 and GS39 may be warranted. Application of foliar fungicides at ear emergence (GS50) is likely to provide reductions in losses;

however, this may not be economically viable. Fertiliser- and seed-applied fungicides are also available for suppression of scald; however, with the exception of Systiva® (active ingredient fluxapyroxad), they are effective only at the seedling stages and therefore crops need to be monitored and foliar fungicides applied as necessary. [23]

9.8 Net blotch

Net blotch is a stubble-borne fungal foliar disease occurring more frequently in the medium and high rainfall areas of the WA wheatbelt. It can reduce grain yield and quality. [24]

There are two types of net blotch present in Australia. The net type net blotch (NTNB), caused by the fungus *Pyrenophora teres* f. *teres*, is currently less common in south-eastern Australia because the majority of barley varieties are resistant, but it can be more damaging. The spot type net blotch (STNB), caused by *Pyrenophora teres* f. *maculata*, is more common, due to the widespread cultivation of susceptible varieties, especially in Victoria where recent surveys have estimated it to be present in >95% of crops.

Spot type net blotch—symptoms

Symptoms are most commonly found on leaves, but occasionally on leaf sheaths and develop symptoms develop as small circular or elliptical dark brown spots surrounded by a chlorotic zone of varying width (Photo 6). These spots do not elongate to form the net-like pattern characteristic of the net form. The spots may grow in diameter to 3–6 mm. Older leaves will generally have a larger number of spots than younger leaves.

Photo 6: *Typical symptoms of spot type net blotch*

Source: GRDC

23 CropPro (2014) Foliar diseases of barley. GRDC/Government of Victoria, http://www.croppro.com.au/crop_disease_manual/ch02s04.php

24 DAFWA (2015) Diagnosing net type net blotch. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2551

VIDEO

GCTV15: Net form net blotch

Net type net blotch—symptoms

The net type net blotch starts as pinpoint brown lesions, which elongate and produce fine, dark-brown streaks along and across the leaf blades, creating a distinctive net-like pattern. Older lesions continue to elongate along leaf veins, and often are surrounded by a yellow margin (Photo 7).

The fungal disease net form of net blotch is becoming more virulent and barley growers need to check variety disease guides and sowing guides when planning what to sow next season.

Photo 7: *Typical netting symptoms of net type net blotch.*

Disease cycle

The disease cycles for the two types of net blotch differ; net type can be carried over on seed, whereas spot type is not seed-borne. Carryover of NTNB occurs when humid conditions are present at crop maturity (Figure 3). Primary inoculum of both types of net blotch comes from infected stubble. Net blotch can survive on infected barley stubble as long as the stubble is present on the soil surface. However, the inoculum levels are typically significantly reduced after 2 years.

Ascospores are produced by pseudothecia on the stubble residues (Photo 8), which are spread by rain-splash or wind to infect neighbouring plants. Most of these ascospores travel only short distances within the crop. Infection requires moist conditions with temperatures ≤25°C, but is most rapid at 25°C.

Secondary infection is provided by conidia produced from lesions on leaves. These lesions usually start on the lower leaves, which then infect the upper leaves during moist conditions. The likelihood of infection decreases with distance from the source. As the barley plant begins to senesce, the fungus grows into the stem as a saprophyte. After harvest, it survives on the stubble and it will begin to produce ascospores when cool moist conditions are present. There is a positive relationship between the quantity of ascospores produced and stubble load. Stubble breakdown and inoculum production may be prolonged during seasons with dry summer months.

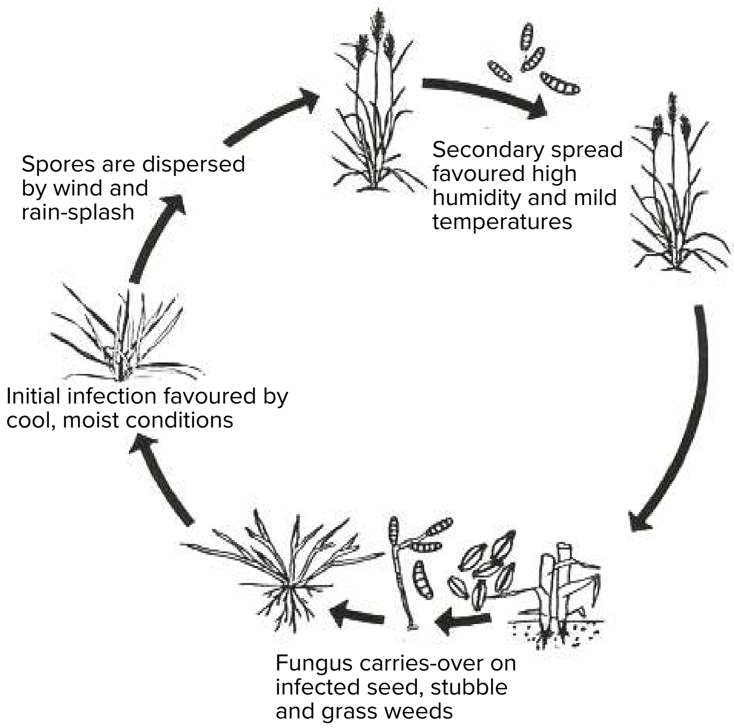

Figure 3: *Disease cycle of net form of net blotch of barley.*

Photo 8: *Pyrenophora teres (a) stubble with pseudothecia, (b) ascospore, (c) conidia.*

Economic importance

When a net blotch epidemic is severe, it can cause significant reductions in grain yield and quality, leading to downgrading of grain from malting quality to feed. In general, the flag and flag-1 leaves must be infected for yield loss to occur, with losses from the net type generally ranging between 10% and 20%, and losses of >30% reported. Spot type net blotch, although common early in the season, rarely develops sufficiently in spring to cause significant yield loss. If yield losses do occur, they are generally <10%, but in severe outbreaks can exceed 20%. Spot type net blotch more commonly causes reductions to grain quality through reduced grain size.

Management

Varietal selection

Avoid susceptible (S) and very susceptible (VS) varieties; growing a variety with a rating of moderately susceptible (MS) or better will significantly reduce the likelihood of grain yield and quality loss.

Crop rotation

Avoid growing susceptible barley varieties in successive years in the same paddock, because net blotch inoculum will become established. Initially, wind-borne conidia from neighbouring crops or seed-borne inoculum (net type only) will provide infection into the new barley crop. Once net blotch is established, inoculum levels will build up in the stubble residue and produce ascospores and conidia. Paddocks close to infected stubble will receive more inoculum than those more distant. Disease levels will be higher in crops in districts where barley crops are grown in close rotation.

Seed dressings

Seed dressings are ineffective for control of STNB. Seed treatments containing the active ingredient thiram can reduce severity of NTNB in seedlings. Seed treatments containing difenoconazole + metalaxyl can reduce the carryover of seed-borne NTNB. Seed-borne infection is acquired only where the seed source was heavily infected late in the growing season.

Time of sowing

Early sowing favours the development of net blotch and can increases the potential for losses; however, this increased risk of disease should be weighed up against other agronomic factors.

Foliar fungicides

Several products are registered for suppression of NTNB and/or STNB. Monitor barley crops and apply a registered fungicide if required. Research has shown the best suppression of the net blotches is provided by application of foliar fungicide between the beginning of stem elongation (GS31) and flag leaf emergence (GS39). A single application of foliar fungicide may be insufficient to eliminate loss of grain yield and quality in severe cases, and a second application may be warranted. Application of foliar fungicide up until head emergence (GS59) may be economical, but will provide less benefit than if applied prior to flag emergence. [25]

Climate and control

Research from WA over 17 years has revealed that the likelihood of a yield response and improved returns from controlling even low levels of STNB is very good unless there is a dry spring; then the response halves.

The studies showed the crop yield response from fungicide applications tended to increase with growing season rainfall.

Spring rainfall, particularly rainfall and number of rainy days in September, determines the likelihood of a yield response to fungicide application. Growers in the medium and low rainfall areas need to take the spring rainfall outlook into account when deciding if a second fungicide application is necessary. In a dry spring there is no additional benefit from a second application.

Controlling STNB in medium and high rainfall areas was most profitable with a double spray at stem extension and then again from flag emergence to half head emerged. [26]

Fungicide resistance

A study conducted by researchers at the Centre for Crop and Disease Management, Curtin University, has shown that NTNB has reduced sensitivity to the fungicide tebuconazole. Researchers also recorded a smaller reduction in sensitivity to other related fungicides, such as epoxiconazole, prothioconazole and propiconazole.

In order to have any chance of slowing down the rise of resistant mutations, growers and agronomists must think of chemical applications as complementary to disease

25 CropPro (2014) Foliar diseases of barley. GRDC/Government of Victoria, http://www.croppro.com.au/crop_disease_manual/ch02s04.php

26 A Hills et al. (2016) Yield response to fungicide control of barley spot type net blotch in Western Australia. 2016 GRDC Western Research Update, 29 Feb–01 Mar 2016. http://www.giwa.org.au/2016researchupdates

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DAFWA (2016) Managing net-type net blotch and spot-type of barley in Western Australia.

DAFWA (2016) Managing spot type net blotch in continuous barley.

DAFWA (2016) STNB barley risk increase prompts management warning.

GRDC (2016) Stubbles set scene for disease tactics. Ground Cover Issue 125.

Curtin University (2016) Researchers discover fungicide-resistant barley disease. Media release.

Cereal Leaf and Stem Diseases (2000 Edition) (GRDC012) GRDC Bookshop Free Phone: 1800 110044 Email: ground-cover-direct@canprint.com.au; also available from the National Library of Australia.

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GRDC (2013) Barley yellow dwarf virus. Fact Sheet.

SARDI (2013) Cereal seed treatments 2014.

Agriculture Victoria (2011) Barley yellow dwarf virus.

prevention strategies, as relying solely on fungicides to control disease is no longer sustainable.

Researchers investigated the resistant NTNB fungal populations from barley grown in Kojonup, Beverley, Bakers Hill, West Arthur and Dandaragan.

They also found for the first time, a mutation within the fungal DNA that has changed the shape of the target enzyme, which means the fungicide binds to it less effectively.

They found the resistant NTNB populations are working against fungicides in two key ways: they are producing more fungicide targets (enzymes) and the shape of those targets have changed.

Epoxiconazole, prothioconazole and propiconazole are registered for the control of NTNB, however tebuconazole was not, and growers should be mindful that NTNB may be present when applying tebuconazole to control other barley diseases. This may contribute to NTNB resistance issues in subsequent seasons.

To manage the development of fungicide resistance, stubble management, rotating crops and growing disease resistant cultivars are key.

If fungicide resistance of any disease is suspected, contact the Fungicide Resistance Group by email frg@cutin.edu.au or phone (08) 9266 1204. [27]

9.9 *Barley yellow dwarf virus* (BYDV)

Growers in high-rainfall zones should be proactive and develop a BYDV management plan that includes crop monitoring, green-bridge management, foliar pesticide sprays and pre-sowing seed treatment. These actions will control the aphid populations that spread BYDV.

BYDV transmission

The virus is transmitted from plant to plant by aphids. When aphids feed on plants, their mouthpart, called the stylet, penetrates the leaf epidermis and enters the plant's vascular system (the phloem). Within 15 minutes of feeding, the aphid either contracts the virus (if the plant is already infected) or transmits the disease to the uninfected plant. The infection is restricted to the phloem, where it replicates and blocks phloem tissues, reducing transport of sugars through the leaves. BYDV is a persistent virus, which means an infected aphid will transmit the virus for the rest of its life.

The virus survives from one season to the next in infected summer crops, weeds and host volunteer plants. It can only survive in living tissues and does not survive in stubbles or soils. It is not airborne.

Five species of aphids transfer different types of BYDV. The most common species are the oat aphid (*Rhopalosiphum padi*), the corn aphid (*R. maidis*) and rose grain aphid (*Metopolophium dirhodum*). Trials have found the oat and rose grain aphids occur on wheat and barley and the corn aphid favours barley and is rarely found on wheat. [28]

Symptoms

Symptoms of BYDV infection may take at least 3 weeks to appear. When assessing a paddock for an outbreak, growers should look for the following:

- Sporadic patches of plants that have turned yellow, most defined at the tip of the leaf, extending to the base. Plants may also appear stunted
- Damage to crops along the fenceline. If aphids are moving into the crop from a 'bridge' of adjoining pastures, crops, weeds or grasses, they are likely to attack plants near fencelines first

27 Curtin University (2016) Researchers discover fungicide-resistant barley disease. Media Release 9 September 2016, http://news.curtin.edu.au/media-releases/researchers-discover-fungicide-resistant-barley-disease/?utm_content=bufferdb9fa&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer

28 GRDC (2013) Management tips to avoid yield penalties. Southern Region. Barley Yellow Dwarf Virus Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-BYDV

- Aphids on the crown and lower stem, then leaves. If left untreated, damage will radiate outwards as wingless juvenile aphids crawl to the next plant to feed, spreading the virus [29]
- Leaves may show a slight mottling to a bright yellow colour starting at the tips and moving down to the base of the leaf. Plants will be dwarfed (Photo 9)

Photo 9: *BYDV symptoms in barley. Note the yellowing of the leaf tip.*

Source: Hugh Wallwork, SARDI

Yield loss

All early BYDV infections of cereal plants will result in less aboveground biomass and a less extensive root system. Grain size can be smaller or grain can become shrivelled, which causes lower yields, higher screenings and reduced marketing options. [30]

Additional yield loss by aphid feeding

Growers in high-rainfall areas are encouraged to check for aphids on a regular basis, especially early in the season (autumn) when winged aphids migrate into cereal crops. The autumn flight is most significant because plants are most vulnerable to damage in their early growth phase.

If aphids are observed and there is a concern about aphid feeding damage, it is suggested growers walk throughout the crop and pull up 10–20 plants from a range of locations, inspecting the crown, lower stem and leaves for aphids. In barley, check inside the unfurled leaf at the top of the tiller.

If plants average ≥20 aphids on every second tiller a foliar insecticide spray should be considered. It is likely to be too late for control of BYDV, but yield loss can be reduced by preventing feeding damage.

Predicting infection

The prevalence of BYDV depends on environmental conditions, host–pathogen dynamics and aphid populations.

29 GRDC (2013) Management tips to avoid yield penalties. Southern Region. Barley Yellow Dwarf Virus Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-BYDV

30 GRDC (2013) Management tips to avoid yield penalties. Southern Region. Barley Yellow Dwarf Virus Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-BYDV

The virus is generally worse in seasons with a wet summer (which allows for significant volunteer or green-bridge growth) followed by a mild autumn and winter. However, the aphids are able to survive hot summers in perennial grasses such as perennial ryegrass, kikuyu, paspalum, couch grass and African love grass in permanent or irrigated pasture areas and along waterways.

Winged aphids are able to migrate around the grain-growing region regardless of summer conditions. Growers should not be complacent in dry summers.

BYDV can be caused by relatively few infected aphids if they arrive early in the growing season and are very mobile through the crop.

Management

For grain growers who decide to manage aphids, it is critical to have a control strategy and put it in place before sowing. Do not wait until aphids are found, because infection or damage will have already occurred.

Growers in high-risk areas should treat each year as a 'BYDV year' unless there has been low rainfall over summer and autumn. [31]

Insecticides

Strategic applications of insecticides can be used against the aphids that carry BYDV or cereal yellow dwarf virus (CYDV) to reduce its spread. It is important to protect the crop during the first 10 weeks after emergence. Apply the first pyrethroid spray at 3 weeks after emergence (or 2-leaf stage if aphids easily found). The second pyrethroid spray can be applied at 7 weeks after emergence. In high risk situations, seed dressings containing imidacloprid applied to seed before sowing are recommended for good early season control in addition to a follow-up pyrethroid spray. [32]

BYDV resistance

There is some level of resistance to BYDV in cereals. The barley varieties Gairdner, Bass⍉, Flinders⍉ and Macquarie contain the *Yd2* gene, which gives moderate resistance to BYDV. [33]

Varietal resistance reduces the impact of the virus on plant growth but does not reduce the impact of aphid feeding on plant growth. Varietal resistance to BYDV therefore does not reduce the need to spray for aphids to prevent yield loss from feeding damage once they reach threshold levels in the crop (50% of tillers with 15 or more aphids). [34]

Delayed sowing

Delayed sowing avoids the main autumn peak of aphid flights and can reduce the incidence of BYDV. However, other yield penalties associated with late sowing mean this option is generally considered a poor choice over use of insecticides. Growers in the late-sown high-rainfall areas should note late sowing might coincide with peak spring flights of aphids, resulting in more severe damage.

Green bridge

Management of the green bridge (volunteer cereals and grass weeds) with appropriate herbicides is important for managing BYDV, in addition to the associated benefits of moisture and nutrient conservation. After summer weed control, spraying out perennial grasses near and around cereal paddocks at least 3 weeks before sowing may reduce aphid numbers. [35]

MORE INFORMATION

Cereal Leaf and Stem Diseases (2000 Edition) (GRDC012) GRDC Bookshop Free Phone: 1800 110044 Email: ground-cover-direct@canprint.com.au; also available from the National Library of Australia.

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Agriculture Victoria (2011) Barley yellow dwarf virus.

31 GRDC (2013) Management tips to avoid yield penalties. Southern Region. Barley Yellow Dwarf Virus Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-BYDV

32 DAFWA (2015) Managing barley yellow dwarf virus and cereal yellow dwarf virus in cereals. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/318

33 GRDC (2013) Management tips to avoid yield penalties. Southern Region. Barley Yellow Dwarf Virus Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-BYDV

34 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

35 GRDC (2013) Management tips to avoid yield penalties. Southern Region. Barley Yellow Dwarf Virus Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-BYDV

9.10 Powdery mildew

Powdery mildew is currently under effective control when treated seed or fertiliser is used and resistant cultivars are grown. However, care is needed to maintain this situation to minimise the risk of the pathogen developing into a threat to the industry. [36] With the reduction of plantings of Baudin⁽ᵈ⁾ barley in WA, the incidence and pressure of powdery mildew has been significantly reduced.

Disease life cycle

Barley powdery mildew is caused by *Blumeria graminis* f. sp. *hordei* and is specific to barley and barley grass.

Infections appear as white fluffy patches on the surface of leaves, leaf sheaths, glumes and awns (Photo 10). These colonies produce windborne spores that spread the disease during the growing season (Photo 11).

Mildew that survives over summer on stubble releases new spores under cool, wet conditions during autumn to infect the new crop. The disease can increase rapidly from early tillering.

The fungus consumes carbohydrates needed by the plant for grain filling. Severe early infections of susceptible varieties can result in costly yield losses and quality downgrades from tiller abortion, reduced grain size and crop lodging through weakened stems. [37]

Photo 10: *Barley powdery mildew infections appear as white fluffy patches on the leaf surface. These colonies produce windborne spores that spread the disease during the growing season.*

Source: Ryan Fowler, DAF Qld

36 GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat

37 GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat

Photo 11: *A powdery mildew infection showing the black fruiting bodies (cleistothecia) that allow the disease to survive on stubbles.*

Source: GRDC

Disease conditions

Most infection occurs during early crop growth in autumn and winter. The disease tends to diminish as temperatures rise and humidity declines.

Powdery mildew epidemics are favoured by the following factors:

- infection in the previous season's barley or wheat crop and the fungus carrying over on stubble (only a risk in wheat-on-wheat or barley-on-barley situations)
- infected barley volunteers (for barley crops) or wheat volunteers (for wheat crops), which produce inoculum early in the season
- susceptible varieties
- cool, wet conditions, which activate the release of stubble-borne spores
- mild temperatures (15–22°C)
- high humidity of >70% (note dew or rainfall not needed for infection)
- low light intensity
- crops suffering from K deficiency
- high N nutrition leading to very dense crop canopies
- growers upwind not using control treatments at seeding

Powdery mildew also occurs where thick crops allow high humidity to be maintained over extended periods. [38]

38 GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat

MORE INFORMATION

[Australian Pesticides and Veterinary Medicines Authority.](#)

[DAFWA (2016) Management of powdery mildew in 2016–fungicide resistance.](#)

[DAFWA (2015) Diagnosing powdery mildew in cereals.](#)

[S Gupta et al. (2015) Change in adult foliar disease resistance profiles of barley varieties grown in Western Australia from 2013 to 2015. GRDC Update Paper.](#)

Choose the best variety

The varieties with the highest risk of powdery mildew are Baudin⁽ᴰ⁾ and Litmus⁽ᴰ⁾, although Oxford⁽ᴰ⁾ may now be susceptible in the lower Great Southern in the presence of the *Ml(St)* virulence pathotype.

Genetic resistance is the best form of management against powdery mildew, especially since a mutation of the *CYP51* gene in powdery mildew has resulted in the compromised efficacy of many DMI fungicides (e.g. tebuconazole, triadimefon, flutriafol) in controlling powdery mildew at label rates. Higher value DMI fungicides and alternative modes of action, such as strobilurins (e.g. azoxystrobin), SDHI (e.g. fluxapyroxad) and amines (spiroxamine) have uncompromised activity against powdery mildew. [39]

Monitor the crop

Crops of susceptible varieties should be monitored for powdery mildew when conditions for infection are favourable. Early protective fungicide sprays are much more effective at controlling the disease than sprays aimed at eliminating or reducing existing infections.

This follows where mildew occurs on the leaf sheaths around the lower stems or low in a thick crop canopy. Mildew in the head can be very damaging and it can be effectively treated only if it is controlled in the crop canopy beforehand. If the disease is detected in the early stages, treat to protect the upper leaves and reduce head infection.

At later stages, consider the individual crop and its circumstances including growth stage, potential yield, level of infection and weather when deciding whether to treat. [40]

Fungicides and treatment of crops

Yield losses can be significant if an early infection is not properly brought under control. Fungicides are more efficient as protectants than eradicants, so apply them before the disease becomes established.

All barley crops, except varieties that are rated Resistant, should be treated with a fungicide at seeding. This prevents epidemics starting in autumn and greatly reduces the need for any later sprays. It also reduces the chance of the fungus evolving new virulence or resistance to fungicides.

Treatments applied at seeding (on seed or in-furrow) can give protection for 6–12 weeks from sowing.

If powdery mildew is detected in crops where the variety is rated MS or lower, consider applying an appropriate fungicide immediately to slow the epidemic. A second spray may be required where the fungus persists. Most pathotypes of powdery mildew are resistant to the more common triazole fungicides. Products such as Prosaro® and Amistar® extra will provide improved control (see below for more details).

Where a fungicide is required, use a different chemical from that used at seeding or used previously as a spray. Always use recommended label rates. This will help to reduce the risk of fungicide resistance developing.

A good option is a QoI–DMI (quinone outside inhibitor–demethylation inhibitor) mix for the first foliar spray and a DMI for the second.

In WA, resistance to some of the older fungicides has already developed in powdery mildew populations in barley. This situation arose from the low adoption of effective

39 DAFWA (2016) 2017 Barley variety sowing guide for Western Australia. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/3766

40 GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat

seed treatments, repeated use of the DMI fungicides tebuconazole, flutriafol and triadimenol as foliar sprays, and widespread use of varieties rated VS. [41]

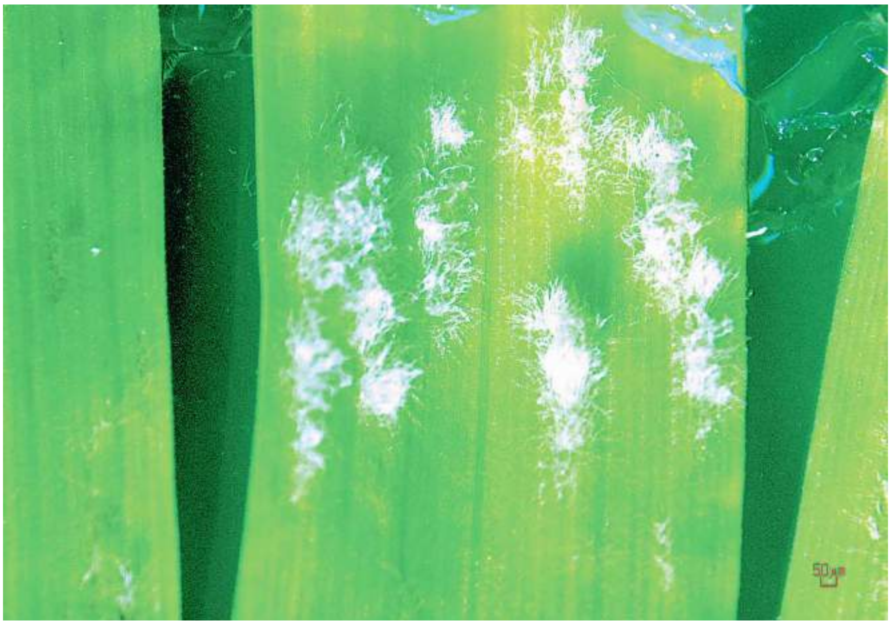

Photo 12: *Triazole resistance in powdery mildew means barley growers should not use tebuconazole alone, flutriafol, triadimefon or triadimenol if powdery mildew is the target disease or if there is a likelihood of it occurring in the season.*

Source: Richard Oliver, Curtin University

Integrated management of powdery mildew

Reduce reliance on fungicides by implementing an integrated disease management approach including:

- Reduce the proportion of area sown to barley varieties rated VS or S to powdery mildew. Where possible utilise varieties with better resistance which may not require fungicides for powdery mildew management. Buloke⁽ᴰ⁾, which is rated MR, has the best level of resistance among current malting varieties
- Control volunteer barley prior to seeding, particularly of susceptible varieties, this will reduce inoculum of powdery mildew (and leaf rust) carried into the season
- Avoid sowing back into barley stubble from highly infected crops, mildew is carried as fruiting bodies on infested stubble
- Avoid growing extremely dense canopies. Dense canopies make it difficult to get adequate penetration of the fungicide and foster ideal conditions for powdery mildew development. Management practices which enhance canopy size include high rates of nitrogen at or just after seeding. Grazing crops before stem elongation can reduce canopy size and may reduce disease pressure without affecting crop yield
- Balance crop nutrition, particularly ensuring adequate potassium [42]

9.11 *Wheat streak mosaic virus* (WSMV)

Wheat streak mosaic virus (WSMV) is a seed- and mite-borne virus that infects cereals (including wheat and barley) and grasses. WSMV is spread by the wheat curl mite (*Aceria tosichella*), which is ~0.2 mm long and can only be seen with magnification. The mite consumes plant sap from a diseased plant and the virus remains alive

MORE INFORMATION

DAFWA (2011) Management of barley powdery mildew in the face of fungicide resistance. Farmnote 466.

41 GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat

42 DAFWA (2011) Management of barley powdery mildew in the face of fungicide resistance. Department of Agriculture and Food, Western Australia. Farmnote 466. April 11. https://www.researchgate.net/publication/274077218_Management_of_barley_powdery_mildew_in_the_face_of_fungicide_resistance

in the mite's mouthparts, being transmitted to other plants as the mite feeds and moves between plants. Wheat curl mites cannot survive for long away from living plant material.

WSMV requires a green-bridge to survive between growing seasons. Substantial yield losses are likely if infection occurs early.

What to look for:

- Symptoms are seen in warm growing conditions, generally before June or from early spring
- Wheat is the most important host of WSMV and all varieties are susceptible to infection
- Barley leaves have necrotic flecks and pale green streaks with older leaves showing yellow along the length (Photo 13)
- Early infected wheat and barley plants are stunted with multiple tillers and have seed heads that contain shrivelled or no grain [43]

Photo 13: *Symptoms of Wheat streak mosaic virus in barley; flecks enlarge and form green to yellow streaks.*

Source: DAFWA

Disease management should involve eliminating the 'green bridge' by controlling:

- cereal volunteers between crops
- grass hosts growing on the borders of areas to be sown to cereals
- grasses in fallows

This means that any green plant material should be dead at least two weeks before sowing the next cereal crop. [44]

9.12 Barley stripe

Barley stripe is a very rare fungal disease that is most often found in irrigated barley. For more information, visit the DAFWA website.

MORE INFORMATION

DAFWA (2016) Wheat streak mosaic virus and wheat curl mite.

DAFWA (2015) Diagnosing wheat streak mosaic virus.

GRDC (2014) Cereal disease update—net blotch, eyespot, wheat streak mosaic virus and white grain. GRDC Update Paper.

GRDC (2009) Wheat curl mite. Fact sheet.

DAFWA (2015) Diagnosing barley stripe.

CropPro (2014) Foliar diseases of barley.

Agriculture Victoria: Rusts of barley

43 DAFWA (2015) Diagnosing wheat streak mosaic virus. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-wheat-streak-mosaic-virus

44 DAF Qld (2012) Wheat—diseases, physiological disorders and frost. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

9.13 Root and crown diseases

Most cereal root and crown diseases (take-all, crown rot, cereal cyst nematode and root-lesion nematode) can be controlled with a one or two year break from susceptible hosts. Break crops must be kept free of grass weeds to be effective. [45]

Barley can incur root and crown diseases, including:

- take-all
- crown rot
- *Pythium*
- *Rhizoctonia*
- cereal-cyst nematode
- root-lesion nematode
- common root rot

9.13.1 Diagnosing root diseases

MORE INFORMATION

Soil Quality (2017) Take-all disease. Fact Sheet.

To determine whether a fungal or nematode root disease is affecting a cereal crop, identify patchy areas of poor crop growth associated with localised disease build-up.

Collect samples of apparently diseased, as well as nearby healthy, plants, taking care not to damage the roots. Wash the soil from the roots and then examine them for indicative symptoms of root and crown diseases. Unthrifty plants may have smaller root mass, fewer root branches, root browning, root clumping or damaged root tips (spear tips) compared with thrifty or well-grown plants nearby. Do not send plant samples that have been washed to a diagnostic laboratory - follow their sampling instructions. [46]

9.14 Take-all

Take-all is a soilborne disease of cereal crops and is most severe on cereal crops in high-rainfall areas. The disease is caused by two variants of the fungus *Gaeumannomyces graminis* var. *tritici* (Ggt). Control of take-all is predominantly cultural and relies on practices that minimise carry-over of the disease from one cereal crop to the next.

The take-all fungus survives the Australian summer in the residue of the previous season's grass host. Cooler temperatures and rainfall in late autumn–early winter encourage the fungus into action. The fungus infects the roots of the emerging crop during this period.

Higher rainfall in winter is likely to increase take-all disease pressure. Lower soil moisture will decrease the chance of severe development of take-all in susceptible plants.

Take-all is suppressed in low pH soils; consequently, paddocks may suffer a sudden increase in take-all severity after they are limed to alleviate soil acidity. Growers planning to apply lime should check the take-all status of paddocks so they can plan to manage these risks in future cereal crops.

Affected plants tend to occur in patches that vary in size from a few plants up to several metres across. Infection causes stunting, with the degree depending on severity. Severe infections may cause premature death of plants after head emergence when the crop becomes water-stressed, resulting in dead plants in an otherwise green crop. In the paddock, take-all is much more obvious on wheat than on barley.

45 G Hollaway, M McLean, J Fanning (2015) Cereal disease guide. AG1160. Revised February 2015. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-disease-guide

46 GRDC (2014) Take-all. GRDC Media Centre, 26 June 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Take-all

Roots of affected plants are dark brown to black through fungal invasion. As the plant matures, the roots become rotten and brittle and the plant can be easily pulled from the soil. Infected plants may have dark brown to black streaks or spots on the base of the stem when the infection is severe.

Take-all causes a blackening of the sub-crown internodes, and of primary and secondary roots. It is best identified by breaking a piece of infected root and observing that the core is jet black. (Common root rot specifically attacks the sub-crown internode causing it to darken brown.).

Whiteheads occur where the head is starved of adequate moisture and nutrients. Both take-all and crown rot cause such extensive damage to the plant roots or lower stems that they are unable to transport these essential supplies up the plant. Take-all damage affects the whole plant and, in the paddock, usually occurs in patches, whereas whiteheads caused by crown rot are frequently confined to single tillers on plants and patches are less obvious, and the crowns are distinctly golden brown. Whiteheads can also be caused by drought, zinc deficiency or early frosts, and will not have the crown or root symptoms caused by disease. [47]

For images and detailed information on identifying cereal root and crown diseases, see the GRDC Cereal root and crown diseases: Back Pocket Guide.

Control

No varieties of barley are resistant to take-all. By far the most effective method of reducing take-all is to remove grasses early in the year before the crop, with a grass-free pasture or break (non-host) crop.

Widespread adoption of minimum tillage has significantly increased the time required for residue to breakdown, and take-all management must reflect this. Burning decreases only the amount of surface residue but does not affect the infected material belowground.

Fungicides, applied as fertiliser, in-furrow or seed treatments, are registered for use to suppress take-all.

Acidifying fertilisers can reduce disease severity but not control the disease. The ammonium form of nitrogenous fertiliser reduces take-all.

Competition from other soil organisms decreases the survival of *G. graminis* in the soil. Summer rains or an early break in the season allows for such conditions, but the effect can be negated by poor weed control during this period. Cereal weeds become infected, enabling *G. graminis* to survive until crop establishment. In addition, rapid drying of the topsoil by weeds decreases the survival of competitive soil organisms, thereby slowing *G. graminis* decline.

Any practice that encourages crop growth will help to overcome the effects of take-all. These include good weed control and the application of adequate fertiliser. [48]

9.15 Crown rot

Crown rot is caused predominantly by the fungus *Fusarium pseudograminearum* which affects wheat, barley and triticale. [49] It survives from one season to the next in the stubble remains of infected plants and grassy hosts. The disease is more common on heavy soils.

Infection is favoured by high soil moisture in the two months after planting. Drought stress during elongation and flowering will lead to the production of 'deadheads' or 'whiteheads' in the crop. These heads contain pinched seed or no seed at all. [50]

47 GRDC (2014) Take-all. GRDC Media Centre, 26 June 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Take-all

48 GRDC (2014) Take-all. GRDC Media Centre, 26 June 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Take-all

49 S Simpfendorfer, M Gardner (2013) Crown rot: be aware of the balancing act or the fall may be harder. GRDC Update Papers, 25 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Crown-rot-be-aware-of-the-balancing-act-or-the-fall-may-be-harder

50 DAF Qld (2012) Wheat—diseases, physiological disorders and frost. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

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D Hüberli et al. (2015) Crown rot yield loss variety trials – barley and wheat.

GRDC (2016) Tips and Tactics: Crown rot in cereals Western Region. Fact sheet.

GRDC (2013) Crown rot: be aware of the balancing act or the fall may be harder. GRDC Update Paper.

DAFWA (2015) Diagnosing crown rot of cereals.

DAFWA (2015) Diagnosing take-all in cereals.

DAFWA (2015) Diagnosing root rot in cereals.

D Hüberli et al. (2015) Crown rot yield loss variety trials – barley and wheat.

The disease may be managed through planting partially resistant varieties, inter-row sowing or crop rotation. If the disease is severe, rotation to a non-susceptible crop for at least 2 years, and preferably 3 years, is recommended.

When infected plant residues come in contact with growing cereal plants, crown rot infection can occur. Even minute pieces of residue can infect plants and a paddock with little visible stubble may still have a crown rot risk. Infection is favoured by moderate soil moisture at any time during the season. Infection occurs through the coleoptile, sub-crown internode, crown and/ or outer leaf sheaths at the tiller bases. The fungus spreads up the stem during the season, with most inoculum being found near the base of the plant. [51]

Symptoms

- Tiller bases are always brown, often extending up 2–4 nodes
- Some tillers on diseased plants may not be infected
- Whitehead formation is most severe in seasons with a wet start and dry finish.
- Plants often break off near ground level when pulled up
- Plants are easy to pull up in good moisture situations because they have little root structure
- Cottony fungal growth may be found inside tillers
- Pinkish fungal growth may form on lower nodes, especially during moist weather.
- Pinched grain is observed at harvest [52]

Infection is characterised by a light honey-brown to dark brown discoloration of the base of infected tillers (Photo 14). In moist weather, a pink-purple fungal growth forms inside the lower leaf sheaths and on the lower nodes.

Major yield loss from the production of whiteheads is related to moisture stress post-flowering. [53]

Photo 14: *Basal browning indicating crown rot infection.*

Source: NSW DPI

51 GRDC (2016) Tips and Tactics: Crown rot in cereals Western Region. GRDC Fact sheet, https://grdc.com.au/Resources/Factsheets/2016/02/Crown-rot-in-winter-cereals

52 K Moore, B Manning, S Simpfendorfer, A Verrell (2005) Root and crown diseases of wheat and barley in northern NSW. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/159031/root-crown-rot-diseases.pdf

53 S Simpfendorfer, M Gardner (2013) Crown rot: be aware of the balancing act or the fall may be harder! GRDC Update Papers, 25 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Crown-rot-be-aware-of-the-balancing-act-or-the-fall-may-be-harder

MORE INFORMATION

GRDC (2012) Seedborne fusarium tests crown rot strategies. GRDC Ground Cover Issue 98.

Effect of sowing time

There is little impact of time of sowing on the incidence of crown rot infection. However, disease severity (as measured by basal browning) and yield loss increases with later sowing.

Sowing a variety early in its sowing window will help minimise the detrimental effects of any crown rot infection by bringing the grain filling period forward into slightly reduced evaporative stress conditions. However, this should be balanced against any increase in the risk of frost damage. [54]

Crown rot phases

There are three distinct and separate phases of crown rot—survival, infection and expression. Management strategies can differentially affect these phases:

- **Survival.** The crown rot fungus survives as mycelium (cottony growth) inside winter cereal and grass weed residues that it has infected. The crown rot fungus will survive as inoculum inside the stubble for as long as the stubble remains intact, which varies greatly with soil and weather conditions; decomposition is generally a very slow process.
- **Infection.** Given some level of soil moisture, the crown rot fungus grows out of stubble residues and infects new winter cereal plants through the coleoptile, sub-crown internode or crown tissue, which are all below the soil surface. The fungus can also infect plants above the ground right at the soil surface through the outer leaf sheathes. However, with all points of infection, direct contact with the previously infected residues is required, and infections can occur throughout the whole season given moisture. Hence, wet seasons favour increased infection events, and when combined with the production of greater stubble loads, disease inoculum levels build up significantly.
- **Expression.** Yield loss is related to moisture and temperature stress around flowering and through grainfill. Expression is also affected by variety and crop type. Moisture stress is believed to trigger the crown rot fungus to proliferate in the base of infected tillers, restricting water movement from the roots through the stems, and producing whiteheads that contain either no grain or lightweight, shrivelled grain. The expression of whiteheads (Photo 15) in plants infected with crown rot (i.e. that still have basal browning) is restricted in wet seasons and increases greatly with increasing moisture stress during grainfill. [55]

Photo 15: *The expression of whiteheads is restricted in wet seasons, so they are not considered the best indicator of crown rot; look for signs of basal browning instead.*

Source: GRDC

54 GRDC (2016) Tips and Tactics: Crown rot in cereals Western Region. GRDC Fact sheet, https://grdc.com.au/Resources/Factsheets/2016/02/Crown-rot-in-winter-cereals

55 S Simpfendorfer, M Gardner (2013) Crown rot: be aware of the balancing act or the fall may be harder! GRDC Grains Update Papers, 25 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Crown-rot-be-aware-of-the-balancing-act-or-the-fall-may-be-harder

Management

Managing crown rot requires a three-pronged attack:

1. Rotate crops
2. Observe plants for basal browning
3. Test stubble and/or soil

Top tips:

- Although many growers look for whiteheads to indicate crown rot, basal browning is a better indicator of the presence of inoculum
- Keep crown rot inoculum levels low by rotating with non-host crops and ensuring a grass-free break from winter cereals. Consider crops with dense canopies and early canopy closure such as canola, mustard or faba beans
- Match N application to stored soil moisture and potential yield
- Limit N application prior to and at sowing to avoid excessive early crop growth
- Ensure zinc nutrition is adequate
- Sow on the inter-row if possible when sowing cereal after cereal [56]
- Current seed treatments do not offer any control

Crop rotation

Growing non-host break crops remains an important tool for managing crown rot, because break crops allow time for decomposition of winter cereal residues that harbour the crown rot inoculum. Canopy density and rate of canopy closure can affect the rate of decomposition and these vary with different break crops (i.e. canola and faba bean). Crops that are sparser in nature, such as chickpeas, are not as effective.

Row spacing and seasonal rainfall during the break crop also affect decomposition and hence survival of the crown rot fungus. Break crops can further influence the expression of crown rot in the following winter cereal crop through the amount of soil water they use (and therefore leave) at depth and their impact on the build-up of root-lesion nematodes.

Growing barley before wheat in paddocks with high crown rot inoculum is not an option because of risk of yield loss. All current barley varieties are very susceptible and they will encourage considerable build-up of inoculum. However, barley rarely suffers significant yield loss from crown rot, largely because its earlier maturity limits the impact of the moisture-stress interactions with infection that result in the production of whiteheads. [57]

Inter-row sowing

Infection rates can be reduced by sowing between intact rows of previous standing cereal stubble. In WA inter-row sowing using accurate ± 2 cm differential GPS autosteer has been shown to decrease the number of infected plants by about 50%, resulting in a 5–10% yield advantage in the presence of crown rot. [58]

Stubble burning

Burning removes the aboveground portion of crown rot inoculum but the fungus will still survive in infected crown tissue belowground; therefore, stubble burning is not a 'quick fix' for high-inoculum situations. Removal of stubble residues through burning will increase evaporation from the soil surface and affect fallow efficiency. A 'cooler' autumn burn is therefore preferable to an earlier, 'hotter' burn because it minimises the negative impacts on soil moisture storage while still reducing inoculum levels.

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56 GRDC (2011) Stop the rot: rotate, observe, test. GRDC Media Centre, 22 February 2011, http://www.grdc.com.au/Media-Centre/Media-News/National/2011/02/Stop-the-crown-rot-Rotate-Observe-Test

57 K Moore, B Manning, S Simpfendorfer, A Verrell (2005) Root and crown diseases of wheat and barley in northern NSW. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/159031/root-crown-rot-diseases.pdf

58 GRDC (2016) Tips and Tactics: Crown rot in cereals Western Region. GRDC Fact sheet, https://grdc.com.au/Resources/Factsheets/2016/02/Crown-rot-in-winter-cereals

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GRDC (2011) Stubble management. Fact Sheet.

GRDC (2013) Stubble management still a burning question. GRDC Ground Cover Issue 107.

Varietal resistance or tolerance

Resistance is the ability to limit the development of the disease, whereas tolerance is the ability to maintain yield in the presence of the disease. Published crown rot ratings are largely based on the evaluation of resistance.

9.16 Pythium root rot

Pythium root rot (caused by several species of *Pythium*) is a widespread fungal root disease that attacks seedlings but rarely causes large yield losses.

Symptoms

In the paddock, patches or whole paddocks may have very poor growth with affected plants more obvious in wetter parts of a paddock (Photo 16, left). Affected plants occur in patches where soil is wetter.

Seedlings are pale and stunted (Photo 16 middle). Older plants have fewer tillers and may rot and die. Roots are stunted, short and stubby with few laterals and root tips (Photo 16, right). Root tips often water-soaked and develop a soft yellow to light brown rot.

Photo 16: *Symptoms of Pythium root rot: left, patches of poor growth; middle, seedlings are pale and stunted; right, roots are stunted.*

What else could it be?

Rhizoctonia root rot in cereals presents similar patches of stunted plants and dead roots. However, Rhizoctonia root rot has 'spear-tipped' roots and patches are more distinct.

Waterlogging in cereals causes stunted plants with dead or dying roots similar to Pythium root rot. However, waterlogged roots are not stubby and have water-soaked tips.

Where does it occur?

Pythium root rot occurs:

- in cold, wet situations
- in wet soils and areas of poor drainage
- where seeding is done directly into areas of dense, dying weeds

Management strategies

Use good weed control in the paddock and delay seeding until weeds have decomposed.

Fungicide seed dressings with a *Pythium*-selective chemical such as metalaxyl-M can be applied. [59]

59 DAFWA (2015) Diagnosing Pythium root rot in cereals. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-pythium-root-rot-cereals

9.17 Rhizoctonia disease

Rhizoctonia root rot is an important disease of cereals in the WA grainbelt with yield losses up to 25% being reported. The disease is an ongoing problem in the low to medium rainfall areas, especially on sandy soils and in some areas of the high rainfall zone. Inoculum levels in the medium rainfall zone of the western region have been increasing in the last few years.

The disease is caused by *Rhizoctonia solani* AG8, a fungus that grows on crop residues and soil organic matter and is adapted to dry conditions and lower fertility soils. The fungus causes crop damage by pruning newly emerged roots (spear-tipped roots) which can occur from emergence to crop maturity (Photo 17). The infection results in water and nutrient stress to the plant, as the roots have been compromised in their ability to translocate both moisture and nutrients.

Rhizoctonia can cause uneven crop growth and damage to crown roots. Field trials in WA, including a multi-year trial, showed the effective control of Rhizoctonia disease in cereal crops requires sound management practices spread over more than one cropping season. [60]

Photo 17: *Symptoms of Rhizoctonia disease: left, healthy roots; middle, seedling severely infected; right, crown root fully infected.*

Photos: Sjaan Davey

60 GRDC (2016) Tips and Tactics: Rhizoctonia, Western Region. GRDC Fact sheet, https://grdc.com.au/TT-Rhizoctonia

Photo 18: *Aboveground symptoms of crop unevenness are seen when Rhizoctonia damages crown roots.*

Photo 19: *Rhizoctonia infection of seminal roots results in distinct patches of poor growth.*

Source: Gupta Vadakattu

Identifying risk

PreDicta B™ is a unique, DNA-based service that identifies soilborne pathogens such as Rhizoctonia so that cropping programs can be adjusted before seeding to include strategies to minimise soilborne risk.

Paddocks at high risk of Rhizoctonia disease can also be identified by examining crown roots of cereals in areas of poor growth (not necessarily bare patches) in the previous spring.

Why is Rhizoctonia disease a problem?

Rhizoctonia root rot is difficult to control because the fungus can survive in soil in the absence of a live plant host, on cereal stubbles; this is termed 'saprophytic ability'. [61]

Biology

R. solani AG8 fungus generally occurs in the top 0–5 cm of soil on decaying crop residues. During the growing season levels increase throughout the profile.

It grows through soil as a network of fungal hyphae or filaments.

Inoculum levels increase on the roots of living host plants and decomposing crop residues.

This ability to survive on crop residues is strongly influenced by the soil conditions—soil type, fertility, moisture, temperature and biological activity.

Rhizoctonia disease is often a problem in low fertility, sandy or calcareous soils of western and southern Australia. *R. solani* AG8 can infect and cause spear tips in a wide range of crops including weeds, but multiplies greatest on cereals and grasses. It can cause losses in a range of crops including cereals, pulses, canola and pastures. Of the cereals, oats are the most tolerant followed by triticale, wheat and then barley.

Key factors influencing occurrence and severity

While *R. solani* AG8 fungus is likely to be present in many soils, it is not necessarily going to cause a problem. One reason for this is beneficial soil microorganisms and high microbial activity have been shown to suppress the expression of the disease and reduce the level of disease.

The move towards minimal till has resulted in conditions more favourable to the disease.

In cereals, *R. solani* AG8 inoculum builds up from sowing to crop maturity and generally peaks at crop maturity, while rain post-maturity of a crop and over the summer fallow causes a decline in inoculum (Figure 4).

Crown root infection late into the crop season results in the build-up of inoculum in cereal crops.

In the absence of host plants, including weeds, summer rainfall events of >20 mm in a week can substantially reduce the level of inoculum. Dry spells, on the other hand, offer little opportunity for stubble breakdown, with disease levels likely to remain stable if a host, or stubble, are present. In cropping systems with stubble retention, suppressive activity has increased over five to eight year period. [62]

61 GRDC (2016) Tips and Tactics: Rhizoctonia, Western Region. GRDC Fact sheet, https://grdc.com.au/TT-Rhizoctonia

62 GRDC (2016) Tips and Tactics: Rhizoctonia, Western Region. GRDC Fact sheet, https://grdc.com.au/TT-Rhizoctonia

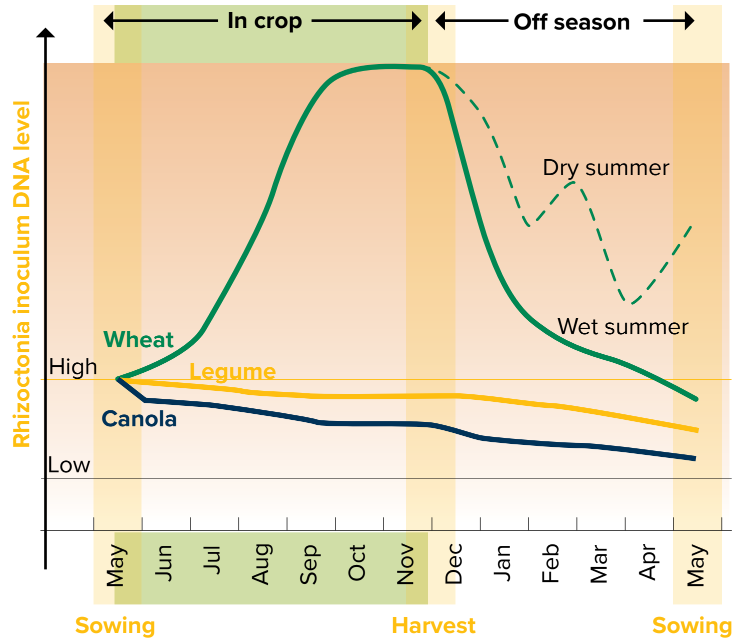

Figure 4: *Rhizoctonia solani AG8 inoculum in soil builds up in-crop and declines during summer following rainfall under wheat (and similarly in barley). By comparison, inoculum levels decline in-crop under grass-free canola and legume crops.*

Source: GRDC

Management strategies

Summer weed control

Summer weed control will reduce inoculum levels and the disease in the following winter by decreasing the availability of living host plants. This complements the moisture- and N-conservation benefits of summer weed control.

Crop choice and rotations

Cereals and grassy fallows promote the build-up of Rhizoctonia inoculum, with barley being the worst of these. Crop rotation with a grass-free, non-cereal crop is one of the best available management strategies to reduce Rhizoctonia disease impact (Table 4). Monitoring of 184 focus paddocks located mainly in the medium rainfall zone of WA over five cropping years (2010–2014) showed canola, fallow, and faba bean reduced Rhizoctonia inoculum levels.

Fungicide treatments

Fungicide treatments need to be used as part of an integrated management strategy/package.

Responses in barley are greater than in wheat and these responses can vary between seasons with the greatest responses occurring when spring rainfall is above average. In GRDC-funded trials in WA and SA, on average seed treatments gave 5% (0–18%) yield responses in wheat and barley.

Several products have been registered for liquid banding. GRDC funded research has shown:

- Product(s) registered for dual banding, in-furrow 3–4 cm below the seed and on the surface behind the press wheel, gave the most consistent yield and root health responses across seasons
- Seed treatment combined with in-furrow application can provide intermediate benefit between seed treatment alone and a split application

Nitrogen

Nitrogen deficient crops are more susceptible to Rhizoctonia disease. Very low levels of mineral-N over summer results from intensive cropping with cereals and stubble retention as soil microbes temporarily utilise all available N while breaking down the low-N stubble residues.

Application of adequate N fertiliser at sowing is necessary to ensure early seedling vigour so that plants can push through the layer of inoculum concentrated in the top 10 cm.

Ensure good N nutrition as crops with adequate N will be less affected by the disease.

Seeding systems and tillage

- Soil openers can have a significant influence on disease severity
- Disturbance below seeding depth helps roots to escape infection and reduces disease impact
- Disease risk is greater with single-disc seeders than knife-points
- Tillage can redistribute inoculum to deeper in the soil
- Ensure phosphate is placed close to the seed to help compensate for early root pruning [63]

MORE INFORMATION

DAFWA (2016) Diagnosing Rhizoctonia root rot in cereals.

GRDC (2016) Rhizoctonia. Fact Sheet.

GRDC (2014) Rhizoctonia control improved by liquid banding of fungicides GRDC Update Paper.

Australian Pesticides and Veterinary Medicines Authority

Table 4: *Management of Rhizoctonia disease in cereal crops*

Year 1 crop (Sept-Nov)	**Summer (Dec-April)**	**Season break (April-May)**	**Year 2 crop (May-August)**
Check for inoculum build-up	**Facilitate inoculum decline**	**Select appropriate crop**	**Manage infection and disease impact through management practices**
• Paddocks can often be identified in the previous spring by estimating the area of bare patches and/or zones of uneven growth during spring – verify that poor plant growth is due to *Rhizoctonia* disease	• In wet summers, early weed control will reduce inoculum. In dry summers, inoculum levels do not change • Adopt practices that prolong soil moisture in the upper layers (e.g. stubble retention and no cultivation) which helps maintain higher microbial activity • Consider soil testing for pathogen inoculum level (PreDicta B™ test in Feb-March), to identify high disease risk paddocks, if disease is not confirmed in the previous cereal crop and especially if planning to sow cereals back on cereals	• Select a non-cereal crop (e.g. canola or pulses) to reduce inoculum levels • Remove autumn 'green bridge' before seeding with good weed control	• Sow early; early-sown crops have a greater chance of escaping infection • Use soil openers that disturb soil below the seed to facilitate root growth – knife points reduce disease risk compared to discs • Avoid pre-sowing SU herbicides • Supply adequate nutrition (N, P and trace elements) to encourage healthy seedling growth • Avoid stubble incorporation at sowing to minimize N deficiency in seedlings • Consider seed dressings and banding fungicides to reduce yield loss • Remove grassy weeds early • Apply nutrient/trace elements, foliar in crop, if required

63 GRDC (2016) Tips and Tactics: Rhizoctonia, Western Region. GRDC Fact sheet, https://grdc.com.au/TT-Rhizoctonia

9.18 Common root rot

Common root rot is a soil-borne fungal disease that attacks wheat, barley and triticale. It is caused by the fungus *Cochliobolus sativus* and it survives from one season to the next through fungal spores, which remain in the top layer of the soil. The disease increases in severity with continuous wheat and with wheat–barley sequences.

Barley increases the soil population of fungal spores rapidly. Infection is favoured by high soil moisture for 6–8 weeks after planting.

Symptoms of common root rot:

- dark-brown to black discoloration of the stem just below the soil surface
- black streaks on the base of stems
- slight root rotting

Common root rot can cause yield losses of 10–15% in susceptible varieties.

The disease may be controlled by planting partially resistant varieties or by crop rotation. Where the disease is severe, rotation to non-susceptible crops for at least two years is recommended.

MORE INFORMATION

GRDC Cereal root and crown diseases. The Back Pocket Guide.

9.19 Smut

Seed treatments provide cheap and effective control of bunt and smut diseases. Seed should be treated every year with a fungicide as without treatment, bunt and smut can increase rapidly, resulting in unsaleable grain. Good product coverage of seed is essential and clean seed should be sourced if a seedlot is infected. Note fertiliser treatments do not control bunt and smuts, so seed treatments are still required.

Bunt or stinking smut or covered smut

Covered smut of barley is caused by the fungus *Ustilago segetum* var. *hordei* (*U. hordei*). This is a different fungus from the cause of covered smut of wheat. This disease is generally well controlled because of the regular use of seed treatments.

Symptoms

Affected plants usually do not show symptoms until ear emergence. Infected ears typically emerge at the same time or slightly later than that of the healthy stems. Also, infected ears often emerge through the sheath below the flag leaf. All of the florets of infected ears are replaced by masses of dark brown to black spores. The spores of covered smut are held more tightly than those of loose smut (Photo 20).

Photo 20: *Covered smut on barley.*

Life cycle

During harvest the spores of affected heads spread and contaminate healthy grain. At sowing the smut spores germinate at the same time as the seed and infect the germinating plant. Infection of seedlings is favoured by earlier sowing as the fungus prefers drier soils and temperatures of 15–21°C. The fungus grows systemically within the plant, usually without producing symptoms, and then it replaces the young grain with its own spores.

Receival standards

Grain Trade Australia's commodity standards have a nil tolerance for bunt in all grades of barley.

Control

All barley seed should be treated with a fungicide for control of smuts each year to stop any buildup of smut in crops. [64]

Loose smut

Loose smut of barley, like wheat, is caused by the fungus *Ustilago tritici* (U. *nuda*). However, the strain of loose smut that attacks wheat does not attack barley and vice-versa.

64 G Hollaway (2012) Bunts and smuts of cereals. Agriculture Victoria, AG1257 (updated July 2013), http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/bunts-and-smuts-of-cereals

What to look for

Until ear emergence, affected plants often do not exhibit symptoms. Affected heads usually emerge before healthy ones and all of the grain is replaced with a mass of dark brown spores (Photo 21). Initially, the spores are loosely held by a thick membrane, which soon breaks releasing the spores onto other heads. Finally, all that remains is bare stalks where the spores once were.

Life cycle

Ears of infected plants emerge early. The spores released from the infected heads land on the later emerging florets and they infect the developing seed. Infection during flowering is favoured by frequent rain showers, high humidity and temperatures of 16–22°C.

There are no visible signs of infection because the fungus survives as dormant hyphae in the embryo of the infected seed. When infected seed germinates, the fungus grows within the plant. As the plant elongates the fungus proliferates within the developing spike, and spores develop instead of healthy grain. Eventually the barley head is replaced by a mass of spores, ready to infect healthy plants.

Photo 21: *Loose smut of barley.*

Receival standards

The Grain Trade Australia commodity standards have a maximum tolerance of 0.1 gram of smut pieces per half litre in all grades of barley.

MORE INFORMATION

[DAFWA (2016) Controlling barley loose smut in 2016.]

[DAFWA (2015) Smut and bunt diseases of cereal– biology, identification and management.]

http://www.giwa.org.au/

Control

Using systemic seed treatments every year will effectively control this disease. It is important to have good coverage of seed if growing a susceptible variety such as Hindmarsh⁽ᴰ⁾.

Loose smut was observed in Hindmarsh⁽ᴰ⁾ barley crops despite use of seed treatment. Tests by SARDI showed that products with triadimenol, flutriafol, tebuconazole and ipconazole may not provide total smut control. The new SDHI fungicide products (EverGol™ Prime and Vibrance®) appeared to provide good control at the high rates recommended for Rhizoctonia. Vitavax 200FF provided good control at both recommended rates. La Trobe⁽ᴰ⁾ is likely to be similar to Hindmarsh⁽ᴰ⁾. [65]

65 G Hollaway, M McLean, J Fanning (2015) Cereal disease guide. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-disease-guide

Plant growth regulators and canopy management

10.1 Canopy management

Canopy management is the manipulation of the green surface area of the crop canopy to optimise crop yield and inputs. It is based on the premise the crop's canopy size and duration determine its photosynthetic capacity and therefore its overall grain productivity.

Adopting canopy-management principles and avoiding excessively vegetative crops may enable growers to achieve a better match of canopy size with yield potential, as defined by the available water. Other than sowing date, plant population is a starting point for the grower to influence the size and duration of the crop canopy. [1]

Canopy management includes a range of crop-management tools for crop growth and development. One of the main tools available to growers is the rate and timing of applied nitrogen (N). [2]

Canopy management in WA

Canopy-management trials in wheat near Wagin, WA, indicate medium plant density (120 plants/m^2) and tactical N applications during the growing season can pay off with higher yields—especially in years with a drier-than-average finish. [3]

Yields can be compromised if plant density is too high (180 plants/m^2) and if too much N is applied at seeding.

Trial sites were set up from 2011 to 2013 at east Wagin, Kulin, Kellerberrin and Kojonup to investigate canopy-management parameters for WA cropping regions. At each site, researchers monitored how wheat canopy density affected grain yield and quality and the level of disease and frost damage. [4]

In the Wagin environment, in a low-to-average-rainfall year, growers can target medium sowing rates and be more flexible in applying N to play the season as it unfolds—without affecting yield.

Restricting canopy growth can conserve soil moisture, reduce disease pressure and allow crops to finish better. Split N application is a good risk-mitigation strategy, especially if the long-term forecast is not promising or if subsoil moisture levels are low.

While this research was conducted on wheat, it clearly shows that there is potential in WA to implement canopy management for barley.

10.1.1 Importance of canopy management

Nitrogen application at stem elongation is associated with higher protein levels. Therefore, growers of malting barley need to be aware that although delayed timing of N can be useful in barley, higher protein content may need to be countered with lower total N doses if a greater proportion of N application is moved from seedbed to stem elongation. [5]

MORE INFORMATION

GRDC (2015) Canopy management in western region.

GRDC (2014) Crop management guide: Advancing the management of crop canopies.

GRDC (2014) Canopy management, Western Update. GRDC Radio

1 N Poole (2005) Cereal growth stages. GRDC, https://www.researchgate.net/file.PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798

2 G McMullen (2009) Canopy management in the northern grains region—the research view. Northern Grains Alliance, July 2009, http://www.nga.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf

3 GRDC (2015) Canopy management in western region, GRDC, http://grdc.com.au/Media-Centre/Hot-Topics/Canopy-management-in-western-region

4 GRDC (2015) Canopy management in western region, GRDC, http://grdc.com.au/Media-Centre/Hot-Topics/Canopy-management-in-western-region

5 N Poole (2005) Cereal growth stages. GRDC https://www.researchgate.net/file.PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798

If the canopy becomes too big, it competes with the growing heads for resources, especially during the critical 30-day period before flowering. This is when the main yield component (grain number per unit area) is set. Increased competition from the canopy with the head may reduce yield by reducing the number of grains that survive for grainfill.

After flowering, temperature and evaporative demand increase rapidly. If there is not enough soil moisture, the canopy dies faster than the grain develops, leading to the production of small grain.

Excessive N application and high seeding rates are the main causes of excessive vegetative production. Unfortunately, optimum N and seeding rates are season-dependent. Under drought conditions, N application and seeding rates that would be regarded as inadequate under normal conditions may maximise yield, whereas higher input rates may result in progressively lower yields. Alternatively, in years of above-average rainfall, yield may be compromised with normal input rates.

The extreme of this scenario of excessive early growth is haying-off, where a large amount of biomass is produced, using a lot of water and resources. Then, later in the season, there is insufficient moisture to keep the canopy photosynthesising and not enough stored water-soluble carbohydrates to fill the grain. Therefore, grain size and yield decrease.

To attain maximum yield, it is important to achieve a balance between biomass and resources. The main factors that can be managed are:

- plant population
- row spacing
- inputs of N
- sowing date
- weed, pest and disease control.

Of these, the most important to canopy management are N, row spacing and plant population. [6]

10.1.2 Barley trials from the western region

In the high-rainfall zone (HRZ) of WA (Agzones five and six) manipulating the crop canopy in malting barley has had significant effects on grain quality, particularly with the popular cultivar Baudin$^{\phi}$. These quality effects were often at odds with the canopy structure that created the highest yields. The trials on sandy gravel soils after canola with relatively low N reserves (less than 80 kg N/ha) illustrated there was no advantage to delaying N at sowing.

Plant population

Comparing all barley project trials (seven in total), irrespective of location, increasing plant population from approximately 100 plants/m^2 to 150–200 plants/m^2 increased yield. In WA the differences have been small, but statistically significant at one site (Mount Barker).

Baudin$^{\phi}$ with its greater propensity to tiller, has not shown the same yield increases from increasing plant population as were evident with Vlamingh. The response of Baudin$^{\phi}$ to population increases being only 0.05t/ha over the two seasons, compared to 0.13 t/ha with Vlamingh. At the longer season site in southern Victoria the yield increases associated with manipulating plant population were very similar (3–4% – 0.18 t/ ha) but expressed at a higher yield level.

This increase in yield with greater plant population has been associated with consistent positive and negative grain quality effects.

6 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series. Industry & Investment NSW/ NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

Positives

- A reduction in grain protein—an increase of approximately 80–100 plants/m^2 over and above a base population of 100 plants/m^2 reduced grain protein by up to 0.3% in WA and Victorian trials

Negatives

- In the same trials increasing plant population resulted in an increase in screenings, the severity of which was linked to the drought in the spring. In the 2009 season the differences were small and not significant, while in 2010 increasing population had significant effects
- In both seasons Baudin$^{\phi}$ screenings were significantly higher than Vlamingh
- The higher plant population was also associated with a small reduction in grain size and test weight

Different soil nitrogen reserves

In the 2009–10 WA trials, soil N reserves were lower than equivalent trials in the east with low to negligible reserves below 30 cm depth. With soil N reserves lower than 80 kg/N/ha after canola and delaying all of the N until early stem elongation (GS30–31) resulted in significant yield losses in both years. Under these circumstances delaying all the N until spring significantly reduced tiller number compared to N applied in the seedbed (IBS—incorporated by sowing). This effect was seen with all of the barley trials and is similar to wheat.

The trial also found it is not possible to apply all N at GS31 and reach the crop's yield potential. In WA trials with malting barley, delaying N until stem elongation led to a lower number of viable heads at harvest and subsequently lower yields.

Correlations

In these WA malting barley trials, it was not only yield that was reduced by delaying N but quality was also impaired. This was not just in the form of higher grain protein but also increased screenings particularly in 2010 when September and October were particularly dry. [7]

10.1.3 Crop row orientation and spacing

Trials in WA have found that sowing barley east–west instead of north–south could halve annual ryegrass seed production.

7 N Poole and J Hunt (2014) Advancing the Management of Crop Canopies. GRDC Publications, https://grdc.com.au/__data/assets/pdf_file/0019/126406/advancing-the-management-of-crop-canopies-pdf.pdf.pdf

Photo 1: *Measuring light availability to the inter-row space in wheat with a Sunfleck Ceptometer*

Source: Glen Riethmuller, DAFWA

Research on several aspects of crop competition between 2010 and 2012 revealed high cereal seeding rates increased crop competition with weeds, reducing ryegrass seed production, and that barley competes more with weeds than wheat. However, the research into crop row orientation was of particular interest as it represents free weed control.

Ryegrass seed production was halved by sowing east-west compared to north-south, according to the field trials conducted at DAFWA Research Stations in Merredin, Wongan Hills and Katanning in 2010 and 2011.

The trials showed an average ryegrass seed production of 2968 seeds/m^2 in east-west crops, compared to 5705 seeds/m^2 in north-south crops. The only exception was Katanning in 2010, where the ryegrass emerged 2 weeks after the crop, ensuring the crop was highly competitive (regardless of crop orientation or seeding rate). [8]

MORE INFORMATION

UWA (2014) Sow west young man.

Table 1: *Ryegrass seed production (seeds/m^2) for east–west versus north–south sown crops from six trials in south-west Western Australia*

Ryegrass seed production: orientation			
Year	**Location**	**East-west**	**North-south**
2010	Merredin	503	911
2010	Wongan Hills	12	159
2010	Katanning	529	465
2011	Merredin	27	125
2011	Wondgan Hills	2,610	6,155
2011	Katanning	14,112	26,272
Average 51% reduction in ryegrass seed set by sowing east-west			

Source: UWA

8 UWA (2014) Sow west young man. University of Western Australia, http://ahri.uwa.edu.au/sow-west-young-man/

10.1.4 Grazing cereal crops as a management tool

Well-managed, dual-purpose cereals provide producers with an opportunity for increased profitability and flexibility in mixed farming systems. They enable increased winter stocking rates and gevnerate income from forage and grain. Typically, these crops are sown earlier, and are longer season varieties that provide greater dry matter production for grazing. Research has shown to avoid grain-yield penalties, stock must be removed from cereals before the end of tillering (GS30). However, the timing and intensity of grazing during the season can incur yield penalties, particularly when grazing pressure is high and late in the grazing period.

Grazing can sometimes be beneficial to grain production by reducing lodging; in seasons with dry springs, grazing can increase grain yields by reducing water use in the vegetative stages, leaving more soil water for grainfill. The challenge for growers is to find the balance of optimising dry matter removal without compromising grain production. [9]

MORE INFORMATION

GRDC (2012) Grazing wheat and barley—impacts on crop management, lodging and grain yield. GRDC Update Paper.

10.2 Key stages for disease control and canopy management

Barley disease requires careful monitoring. Its lower leaves, which emerge earlier than in wheat, are more important to the plant than the lower leaves in wheat. Other points to consider when using fungicide in barley canopy management:

- The flag leaf is relatively small and unimportant in barley compared with wheat, and its appearance is therefore not a convenient midseason focal point for strategies.
- Earlier, more important, leaves that require fungicide application create a later season gap in protection, therefore making two sprays more effective in this crop (Figure 1).
- Barley often suffers from wet-weather diseases early in the season, but then is subject to drier or warmer weather diseases later in the season, again making it more difficult to target a single-spray program under diverse disease pressure

9 GRDC (2102) Grazing wheat and barley—impacts on crop canopy management. GRDC Update Papers, 23 March 2012, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/431273/Grazing-wheat-and-barley.pdf

MORE INFORMATION

GRDC (2014) Fungicide management and timing keeping crops greener for longer in the high rainfall zone. GRDC Update Paper.

GRDC (2014) Advancing the management of crop canopies.

GRDC (2013) New tools lift canopy management. Ground Cover Issue 105.

GRDC (2009): Disease management and crop canopies. Driving Agronomy Podcast.

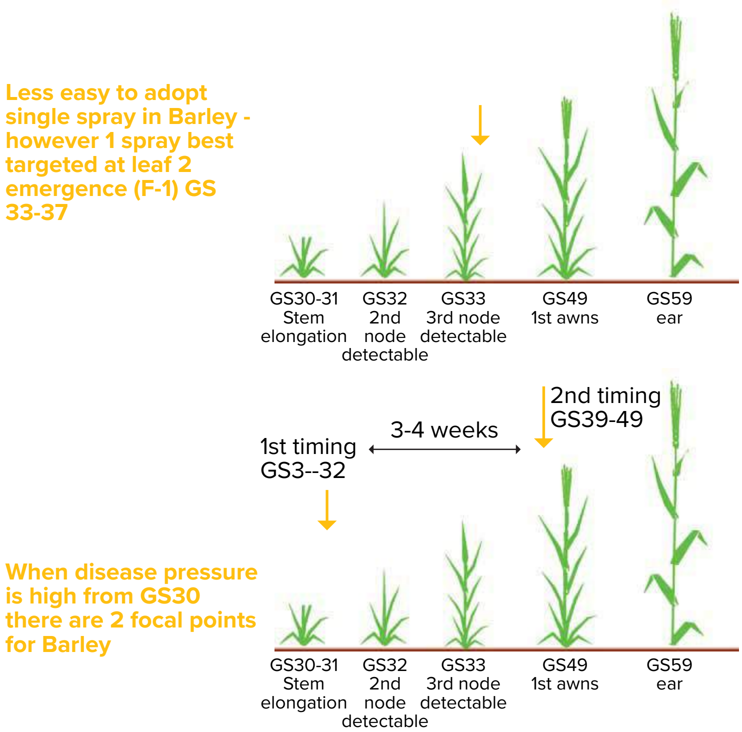

Figure 1: *Key stages for disease control and canopy management.*

Source: FAR

10.3 Use of plant growth regulators

Plant growth regulators (PGRs) may be used to minimise crop lodging and maximise yield, particularly in high-N situations. PGRs have been used routinely in high-input, high-yielding cereal systems in Europe and New Zealand to shorten straw height and reduce the incidence of lodging. Lodging causes significant losses in crop production through reduced movement of water and nutrients and reduced translocation of plant-stored carbohydrates via the stem into the head. Lodging also reduces grain quality and increases harvest losses and the cost of the harvesting process.

Inhibitors of the plant hormone gibberellin and ethylene producers are the two main PGR groups. Research in Australia has focused on gibberellin-inhibitor products, which act by blocking gibberellin biosynthesis to reduce internode length in stems, thereby decreasing plant height. There are several phases in this pathway and different PGRs act at different points. For example, chlormequat (Cycocel®) acts early in the pathway, whereas more recently developed products such as trinexapac-ethyl (Moddus® Evo) act on later stages.

Plant growth regulators are reported to have a yield-enhancement effect by improving the proportion of crop dry matter that is partitioned into grain yield. This effect has been related to a reduction in the plant resources required for stem elongation, with these resources then available for grainfill. Some PGRs have also been associated with increased root growth, resulting in improved water extraction from soil. Yield responses to PGRs are highly variable, with responses ranging from –40% to +2%, depending on product choice, application time, crop or variety and growing-season conditions. [10]

10 M Gardner, R Brill, G McMullen (2013) A snapshot of wheat and barley agronomic trials in the northern grains region of NSW. GRDC Update Papers, 5 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-snapshot-of-wheat-and-barley-agronomic-trials-in-the-northern-grains-region-of-NSW

Use of ethephon has generally been low because responses are viewed as variable, and growers have not regularly seen the benefit of incorporating it into their management programs. There is a lack of understanding of the conditions and situations under which to the use PGRs.

A great deal of resources have been devoted to optimising crop-husbandry strategies to minimise lodging, whereas relatively little has been devoted to identifying the situations in which to use PGRs for optimum results. If the field, variety or growing conditions are not conducive to lodging, the use of a PGR will be of no benefit to the grower; many of the trials undertaken with PGRs have reached conclusions in circumstances where a PGR did not need to be applied in the first place. [11]

Moddus® Evo (trinexapac-ethyl at 250 g/L) is registered for Australian cereal growers to reduce the incidence and severity of lodging and optimise the yield and quality of high yielding wheat, barley and oat crops.

Between 2004 and 2011, field trials with Moddus® Evo were run across Australia by Syngenta, the manufacturer of Moddus® Evo, to investigate the value of applications to Australian cereals in terms of reducing lodging and improving yields. The trials encompassed a range of varieties, climatic conditions and geographical locations, and varied application rates were applied at different growth stages.

Measurements were taken of the effect of Moddus® Evo application on plant growth, stem strength, stem-wall thickness, lodging, lodging score and yield, as well as grain-quality measurements (Figure 2). Several rates of Moddus® Evo were assessed for reduction of lodging and enhancement of yield in barley. Moddus® Evo applied at rates of 300 or 400 mL/ha was consistently found to improve yields and reduce barley lodging (Figure 2a, b). The optimal growth stage for Moddus® Evo application to have the most consistent and greatest impact on yield was GS30–32.

When growth conditions were favourable, a bounce-back effect, where compensation growth occurred, was often observed. To reduce the impact of the bounce-back, a follow-up application of Moddus® Evo was evaluated. With a second application of Moddus® Evo at GS37–39, growth compensation was reduced (Figure 2c). When conditions were favourable for bounce-back, the second application resulted in significant yield improvements. The results in Figure 2d are the average across a number of trials where a second application of Moddus® Evo was applied; not all of the trials favoured bounce-back growth, which has reduced the overall impact. [12]

11 B. Staines, LM Forsyth, K McKee (2013) Moddus Evo: controlling plant growth for reduced lodging and improved cereal yields. GRDC Update Papers, 27 March 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Moddus-Evo-Controlling-plant-growth-for-reduced-lodging-and-improved-yields

12 B. Staines, LM Forsyth, K McKee (2013) Moddus Evo: controlling plant growth for reduced lodging and improved cereal yields. GRDC Update Papers, 27 March 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Moddus-Evo-Controlling-plant-growth-for-reduced-lodging-and-improved-yields

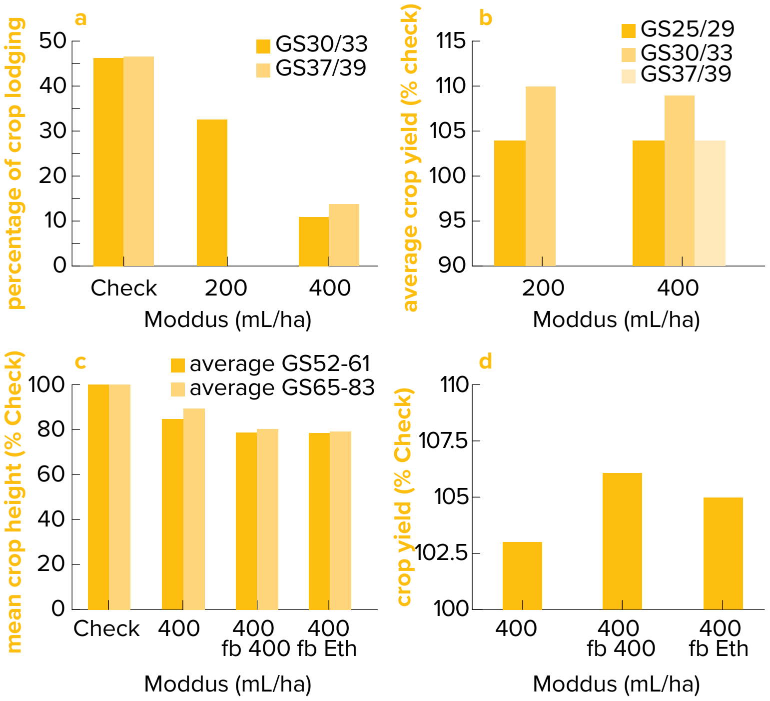

Figure 2: *(a) Effect of Moddus® Evo concentration on lodging when applied at early and late stem elongation in barley crops; data are a summary of multiple trials. (b) Effect of concentration and timing of Moddus® Evo applications on barley yields, data are percentage improvement from untreated. Applications occurred on healthy growing plants, and conditions were not favourable for bounce-back growth. Average data are from five trials run in 2007; 80% of the trials did not have lodging. Effect of second application of Moddus® Evo on (c) barley stem heights and (d) barley yields when conditions favour compensatory growth following initial application.*

Source: GRDC

Overall improvements in yield were often correlated with a reduction in stem height whether or not lodging occurred. Yield improvements through the reduction of lodging are well documented. What is less understood is the impact, often positive, on yields with the use of Moddus® Evo in the absence of lodging.

Conversely, during the evaluation of effects of Moddus® Evo on yield enhancement and reduction in lodging, a few trials had anomalous results, where Moddus® Evo application did not improve yield. Environmental conditions at these trials during the lead-up to Moddus® Evo application were poor, with extensive frosting, drought, poor subsoil moisture profile or nutrient deficiencies within the crop. Therefore it is recommended Moddus® Evo be applied only to healthy growing crops with optimum yield potential.

Syngenta concluded from its trials that Moddus® Evo offers growers in environments conducive to lodging an in-season option to reduce the impact of lodging while allowing them to manage crops for maximal yields. The timing and concentration of Moddus® Evo applications is critical to optimal yield improvements and it should only be applied to healthy growing crops. [13]

MORE INFORMATION

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13 B. Staines, LM Forsyth, K McKee (2013) Moddus Evo: controlling plant growth for reduced lodging and improved cereal yields. GRDC Update Papers, 27 March 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Moddus-Evo-Controlling-plant-growth-for-reduced-lodging-and-improved-yields

Crop desiccation/spray out

Diquat is registered for pre-harvest weed control in barley. See GRDC late season herbicide use fact sheet.

In-crop spray topping with diquat in barley is an effective strategy for controlling a range of annual grasses. It should be used as a tool with other integrated weed management (IWM) techniques such as cutting crops for hay, breakcrops and green and brown manuring. Timing of application and rates of product are crucial to maintaining crop yield while reducing ryegrass seeds.

The application of herbicides late in the season to prevent weeds setting seed or to desiccate crops must be carried out with caution and in line with herbicide label recommendations. It is essential to check if these practices are acceptable to buyers, as in some situations markets have extremely low or even zero tolerance to some pesticide and herbicide residues. There are three reasons to apply non-selective herbicides late in the season:

- to manage late season weeds with an alternative chemical group to that used in-crop
- in-crop spray topping of weeds to prevent seed set;
- for pre-harvest desiccation of the crop and weeds to accelerate or even-up ripening to assist with harvest, especially after a wet spring

Timing is when the crop is fully mature; spraying earlier than this can result in decreased yields and small or shrivelled grain that may be downgraded by the buyers

Diquat, including Reglone®, is the only registered herbicide for pre-harvest weed control in barley. The malting barley industry is opposed to pre-harvest applications of herbicides to barley that may be sold as malt grade. Contact your buyer prior to any pre-harvest applications to malting grade barley.

Some formulations of diquat may be applied by air pre-harvest.

Table 1: *Product registrations for pre-harvest weed control and desiccation vary by crop type. Always check product labels (note: Paraquat/diquat products, for example Spray.Seed® are not registered for pre-harvest weed control or desiccation).*

Crop	Paraquat	Diquat	Glyphosate
Wheat	Paraquat is not registered for: • in-crop spray topping; • pre-harvest crop desiccation; • pre-harvest weed control. **DO NOT USE PARAQUAT PRODUCTS FOR THESE USE PATTERNS** These use patterns are unregistered.	Pre-harvest weed control (all states): Spray as soon as the crop is mature and ready for harvesting. Under wet spring conditions crops can periodically become infested with weeds which seriously interfere with harvest operations. Diquat will control these weeds allowing for efficient harvest. **WHP: NOT required when used as directed.**	Not all glyphosate formulations are registered for this use Apply to mature crop from late dough stage (28 per cent moisture) onwards. The higher rate will be required when crops are heavy and leaf shading effects may occur. DO NOT use on crops intended for seed or sprouting. Where wheat is grown in rotation with any herbicide-tolerant crop, management should be consistent with implementation of any management plan for herbicide-tolerant crops. **WHP: DO NOT harvest within 7 days of application.** **Only weedmaster®DST® can now be applied at higher use rates in wheat with a 5-day harvest witholding period.**

Crop	Paraquat	Diquat	Glyphosate
Barley	Paraquat is not registered for: • in-crop spray topping; • pre-harvest crop desiccation; • pre-harvest weed control. **DO NOT USE PARAQUAT PRODUCTS FOR THESE USE PATTERNS** These use patterns are unregistered.	Winter cereals – pre-harvest weed control (all states): Spray as soon as the crop is mature and ready for harvesting. Under wet spring conditions crops can periodically become infested with weeds which seriously interfere with harvest operations. Diquat will control these weeds allowing for efficient harvest. **WHP: NOT required when used as directed.**	Glyphosate is not registered for: • in-crop spray topping; • pre-harvest crop desiccation; • pre-harvest weed control. **DO NOT USE GLYPHOSATE PRODUCTS FOR THESE USE PATTERNS** These use patterns are unregistered.
Canola	Paraquat is not registered for: • in-crop spray topping; • pre-harvest crop desiccation; • under-the-cutter-bar spraying during swathing or windrowing activities; • pre-harvest weed control; • spraying over the top of swaths or windrows **DO NOT USE PARAQUAT PRODUCTS FOR THESE USE PATTERNS** These use patterns are unregistered.	Pre-harvest crop desiccation (all states): Spray when 70 per cent of the pods are yellow and the seeds are browny or bluish and pliable. Canola ripens unevenly and is prone to pod shatter and seed loss. Direct harvest four to seven days after spraying. **WHP: DO NOT harvest for at least 4 days after application.**	**Only weedmaster®DST® is registered for pre-harvest use in canola.** Apply to mature standing crop from early senescence (minimum of 20% seed colour change to a dark brown/black colour from within the crop) prior to windrowing or direct harvest. Use the higher when crops or weeds are dense and/or where faster desiccation is required. DO NOT use on crops intended for seed DO NOT harvest for 5 days after application to standing crops DO NOT overspray windrows DO NOT apply to standing crops and again at the time of windrowing Refer to the complete weedmaster®DST® label and critical comments section.
Chickpeas Faba beans Field peas Lentils Pigeon peas+ Lupins@ Vetch# Adzuki beans^ Cowpeas^ Mungbeans~ Soybeans~	Spray topping to reduce seed set – annual ryegrass (NSW, Victoria, SA, WA, ACT only). Chickpeas/Faba beans/Field peas/ Lentils/Lupins/ Vetch: Spray the crop when the ryegrass is at the optimum stage, that is when the last ryegrass seed heads at the bottom of the plant have emerged and the majority are at or just past flowering (with anthers present or glumes open) but before haying off is evident – usually October to November. Use of the higher rate in these crops is usually more reliable and gives a greater reduction in seed set. Reduction in crop yield may occur especially if the crop is less advanced relative to the ryegrass; that is, if crops have a majority of green immature pods. The higher rate may also increase any yield reduction. In practice crop losses in excess of 25 per cent may occur. **WHP: DO NOT harvest for 7 days after application.**	Pre-harvest crop desiccation (all states): Dry beans/Dry peas/Pigeon peas/ Lentils/Chickpeas/Faba beans/Lupins/ Soybeans/ Mungbeans: Spray as soon as the crop has reached full maturity. Helps overcome slow and uneven ripening and weed problems at harvest. **WHP: NOT required for dry beans, dry peas, mungbeans when used as directed.** Lentils/Chickpeas/Faba beans: **DO NOT harvest for 2 days after application.** Pigeon peas, Soybeans: **DO NOT harvest for 4 days after application.**	**Not all glyphosate formulations are registered for these uses.** Field peas/Faba beans: Pre-harvest application to reduce viable seed set of annual ryegrass. Adzuki beans*/Chickpeas*/Cowpeas*/Faba beans*/Field peas*/ Lentils*/Mungbeans*/ Soybeans*: Pre-harvest application to desiccate a crop as a harvest aid and weed control – annual weeds. Chickpeas*: Glyphosate + metsulfuron tank mix for pre- harvest application as harvest aid and weed control – annual weeds. **WHP: DO NOT harvest within 7 days of application.** Refer to label for specific timings. *Application to crops intended for seed production or for sprouting may reduce germination percentage to commercially unacceptable levels.

Paraquat only ^ Glyphosate only + diquat only / ~ glyphosate and diquat only @ Paraquat products and diquat only whP withholding period
® registered trademark

Harvest

In Western Australia (WA), barley is generally harvested from October to December, prior to wheat, which provides some spread of harvest timing. Barley yield can be expected to be similar to or better than wheat yield. The crop dries down well and desiccation is generally not necessary unless late weed growth needs to be controlled. [1]

Growers should note that glyphosate is not registered for late season application on malt or food barley in Australia. Any malting barley treated with glyphosate prior to harvest must be declared and will be received as feed grade. [2]

12.1 Pre-harvest swathing

Swathing (also referred to as windrowing) is a simple means of speeding up the drying of grain while retaining quality. Swathing involves cutting the crop and placing it in rows held together by interlaced straws, supported above the ground by the remaining stubble. It involves cutting the crop when the grain has reached the physiological mature stage (moisture usually at 20–30%). The crop is then allowed to dry in the swaths until the moisture content is below 12.5%, when it is harvested using a special pick-up front attachment on the header. Swathing is one of the options more frequently used by growers in the southern coastal areas where the likelihood of rainfall at harvest is highest. [3] It also improves harvest weed seed management techniques because all the weeds are captured in the swath before any seeds have time to shed.

Swathing has many advantages:

- Swathed barley matures more rapidly and is ready to harvest 5–15 days earlier than if left standing. This effectively reduces the period that the crop is exposed to potentially damaging rains and is a cheaper way of drying down the crop
- Yield loss from lodging and head drop is minimised while the crop is in the swath
- Swathing helps even out the maturity of the crop and dry out any green weeds that might contaminate the crop
- Swathed barley is drier than grain in a standing crop so harvest can start earlier in the day and continue later than for a standing crop

These advantages must be balanced against a number of disadvantages, including:

- additional costs in the purchase or contract costs of a swather and an additional pass compared with direct heading
- fewer hectares covered per hour when harvesting (approximately 20% slower);
- a possible increased drying time of a swath in prolonged wet conditions, reducing its quality
- possible collection of soil, rocks, beetles and other material, contaminating the sample

When to swath

Swathing can begin when grain moisture content is below 35% and when the grain is at the medium dough stage and is hard but can still be dented with the thumbnail. It is better to swath early to prevent losses from shedding and lodging, but do not swath when the ground is wet after rain.

Grainfilling studies have shown barley reaches maximum grain weight when all of the green tissue has gone from the flag leaf sheath and the peduncle (stem immediately

1 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

2 GrainCorp (2016) Harvest Alert. http://www.graincorp.com.au/

3 DAFWA (2016) Barley production—harvest and grain quality. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2212

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GRDC (2014): Harvest systems combined to crush weed-seed resistance. Ground Cover 113.

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

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GRDC (2011) Development of the Harrington Seed Destructor.

GRDC (2015) The nuts and bolts of efficient and effective windrow burning.

GRDC (2013) Windrow burning for weed control—WA fad or viable option for the east.

below the head). Avoid swathing too early as the grain is not fully developed and this will give small pinched grain. While it is often easier to swath later than earlier, the swaths of a ripe crop may not interlock well enough to withstand disturbance from a strong wind.

High-yielding crops are likely to gain more from swathing than low-yielding crops. Generally, crops that are likely to yield less than 2 t/ha should not be swathed. [4]

Swathing and harvesting operation

The crop can be swathed in any direction but is usually cut across the sowing direction or at a 45-degree angle for crops with a wider row spacing. This allows the swath to sit up better on the stubble. Swathing is not recommended for paddocks where the crop row spacing is over 25 cm.

Avoid placing swaths in the same location each year. Adjust to distribute the residue across the paddock so nutrients are not concentrated in one place.

Swather size or width of cut should match header capacity. A double-up attachment to the swather or placing two swaths side by side requires a larger capacity header and concentrates the residue in a narrow band within the paddock.

The cutting height must be adjusted to allow for sufficient straw on the head to keep the swath together (minimum 30 cm) and sufficient stubble height to support the windrow. It is recommended to start the swath height at 10–20 cm above the ground (one-third height of crop or 'beer can' height) and then adjust to produce an even swath with well-interlaced straws that sit above the ground, allowing good air circulation and rapid drying should rain occur.

When the swath is picked up, the reel should be rotating slightly faster than ground speed, but not so fast that heads are knocked off the stems. The conveyor canvas should be revolving sufficiently fast so it does not clog with crop material. Rows pick up best when the header follows the direction of the swath (heads first).

If the crop is too thin or the stubble too short to support the swath above the ground, the crop should not be swathed. Heads on the ground may sprout and attempts to pick up heads lying close to the soil surface will pick up soil.

Harvesting of the swathed crop must be completed as soon as possible, ideally within 10 days of swathing. If swaths are left too long and are subjected to long periods of wetting (more than 25 mm of rain over 4 to 8 days), grain may sprout and become stained and possibly contaminated with bronze field beetle. Following extensive rain, some growers have attempted to turn or fluff the swaths using a rake or hay baler with an open back door. There has been mixed success with this practice, particularly with heavy swaths. Many growers have reported in hindsight it would have been better to not have touched the swath row but to have picked up as normal.

One of the major sources of contamination in swath barley is when the stubble is torn out during the swathing operation. This generally occurs when the swather is operated at too high a ground speed or when trying to swath when the straw is tough due to it being cool or damp. [5]

12.2 Harvesting barley in WA

Maintaining the quality of grain is dependent on the correct and timely harvesting of the grain, and its management and storage once removed from the paddock (Photo 1).

4 DAFWA (2016) Barley production—harvest and grain quality. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/2212

5 DAFWA (2016) Barley production—harvest and grain quality, https://www.agric.wa.gov.au/barley/barley-production-harvest-and-grain-quality?page=0,0

Photo 1: *Harvesting barley.*

Source: DAFWA

The harvesting operation is crucial in determining the grain yield and quality of barley. For malting barley, unless the grain has a germination percentage above 98% it is not suitable for sale to maltsters. How the barley grain is handled at harvest is critical as viability of the grain must be maintained.

The reduction in the quality of barley for use in the malting and brewing as well as feed industries may be a result of:

- skinning the grain due to over threshing
- storing wet due to harvesting at high grain moisture without aeration
- drying to temperatures above 43°C

Because of this, the potential for a premium price and the possibility of head loss or weather damage means malting barley should be harvested as soon as the crop is at a moisture content that is suitable for storage (Photo 2).

Photo 2: *Barley heads.*

Source: DAFWA

12.3 Header settings

Harvest and handling are particularly important for malting barley. Even minor damage to the seed can affect its ability to germinate. Cracked grains, skinned or partially skinned grains and grains killed through damage to the germ do not malt properly.

When examining a barley seed sample for damage, look at individual grains and not just a mass of grain. Always examine the back of the grain first and ignore the crease side. Severe cracking and germ damage are nearly always accompanied by a high degree of skinning. The most common causes for this are:

- **Drum speed too high:** use only the slowest drum speed that will effectively thresh the grain from the barley head. A higher drum speed is needed when harvesting crops not properly ripe and can cause serious grain damage
- **An incorrectly adjusted or warped concave.** Check the setting frequently during the day. If the thresher drum speed is correct, concave adjustments should cope with the changes in temperature and other harvesting conditions met during the day

The airflow may need to be increased slightly to obtain a clean sample. The application of heat can also affect germination of grain and this should be taken into account if artificial drying is intended for malting-quality barley. [6]

It is important to note once the moisture in the grain falls below 10%, the grain becomes susceptible to skinning due to over threshing. Skinned barley takes up moisture faster during the steeping phase of the malting process than grain with its husk intact. This can lead to death of the grain because it cannot regulate water uptake or excessive root and shoot growth. For the brewer, this leads to reduced alcohol yield. Skinned grain is very noticeable to grain buyers in the dried malt sample as it turns pink during kilning. Correct set-up of the header is very important to ensure that overthreshing of the barley grain does not occur.

12.3.1 Direct heading of dry barley

The simplest and most common harvesting method for barley is to wait until the grain has ripened and dried to a moisture content of less than 12% so it can be delivered directly to the receival point.

Once the crop is ripe, harvest as soon as possible to reduce the potential losses from wind damage or weathering. It is important when direct heading barley to:

- prevent the skinning and cracking of grain by correctly setting up the harvester
- avoid contamination by ensuring the harvesting and grain movement equipment is clean
- reduce grain losses and damage by monitoring the sample throughout the day and adjust thresher speeds and concave to suit conditions as they change
- use correct screens to remove small grain, weed seed and contaminants

This may cause considerable delays to the harvesting operation and increase the risk of head loss or grain being discoloured by early summer rains.

12.3.2 Monitoring grain loss

Monitoring for grain loss should begin before harvest. A seed count on the ground of >26 seeds in an area 10 cm by 100 cm means a loss of >100 kg/ha. After checking for any grain on the ground prior to harvest, growers should check after beginning harvest to determine any harvest loss. It is recommended that a minimum of 10 counts be taken and averaged. [7,8]

6 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

7 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

8 Agriculture Victoria (2012) Estimating crop yields and crop losses. AG0104, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/estimating-crop-yields-and-crop-losses

FAQ

12.4 Delayed harvest issues and management

Because mature barley does not stand weather damage as well as wheat, it is important not to delay harvest. Lodging can be a problem and patches of unripe crop on headlands and low-lying areas should be avoided, because unripe grains can contaminate samples and cause downgrading. [9]

Delayed harvest can:

- increase the lodging risk resulting in a slower harvest
- reduce grain yield (largely through head loss)
- decease hectolitre weight (through grain swelling)
- decrease screenings (through grain swelling)
- increase or decrease grain brightness (depending on the level and timing of harvest rainfall)
- decrease grain hardness thereby increasing grain breakage during pearling for shochu manufacture
- increase pre-harvest sprouting risk, therefore shortening the optimal storage duration
- influence the sensitivity of the grain to water during steeping in the malt house
- increase the rate of germination

Adverse weather conditions can cause significant delays at harvest, resulting in the crop standing in the field for longer than is ideal. These crucial delays affect not only grain yield, but grain quality traits important for meeting malt barley receival standards. End use traits such as pre-harvest sprouting, dormancy, water sensitivity and grain hardness can also be influenced by harvest timing.

In some cases, delays in harvest can be beneficial, such as bleaching of the discoloured grain due to sunshine, but the negative impacts from delayed harvest usually outweigh the positives.

Delayed harvest impacts

Research conducted in WA evaluated a total of 19 malt (or under malt accreditation) and food barley varieties across six trials at three locations (Gibson, Northam and Katanning) between 2009 and 2011.

The study assessed the effect delays in harvest date might have upon the grain yield and quality of a range of upcoming and existing malt or food barley varieties.

In all barley growing regions, there is always a chance of harvest being interrupted by rainfall. The trial series showed for the varieties assessed, rainfall and delays in harvest can lead to:

- increased lodging risk
- losses of grain yield
- reduced hectolitre weight
- a possible increase or decrease in grain brightness (dependent on the amount and distribution of rainfall at harvest);
- decreased grain hardness and increased pre-germination risk

In the grower's favour was the likely decrease in screenings, with no change expected in grain protein concentration.

For maltsters, delayed harvest can impact processing logistics, the level and rate of germination expected, as well as the steeping program to be used.

Delays in harvest date did not impact one variety more than another for most of the grain quality traits assessed at receival (hectolitre weight, screenings and grain

9 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

protein). There was some evidence however, that Bass⁽ᴾ⁾, Baudin⁽ᴾ⁾ and Flinders⁽ᴾ⁾ may weather or bleach slightly differently to the other varieties evaluated.

Varietal differences were associated with straw strength and risk of head loss. To minimise the risk associated with harvest delays, especially on the south coast of WA, growers should consider sowing only manageable areas of susceptible varieties or look to swath susceptible varieties.

Baudin⁽ᴾ⁾ was the only variety that could be delayed in harvest date by more than 6 weeks in all sites with minimal loss in yield or quality.

Varieties with a high risk of pre-harvest spouting reacted differently (for germination related traits) to delayed harvest than those with a low risk. Whilst those effects on grain quality did not influence the 'receivability' of the barley, they could influence what an end user (ie. maltster) might do with the grain. [10]

Although the trials were conducted between 2009 and 2011, the varieties Baudin⁽ᴾ⁾, Bass⁽ᴾ⁾, Flinders⁽ᴾ⁾ and La Trobe⁽ᴾ⁾ are still commonly grown in WA.

The trials were continued in 2015 and 2016 and this research included newer varieties including Scope CL⁽ᴾ⁾ , Granger⁽ᴾ⁾, Spartacus CL⁽ᴾ⁾ and Compass⁽ᴾ⁾ .

The study found Scope CL⁽ᴾ⁾ is comparable to Buloke⁽ᴾ⁾, which was tested in the original trials, and 2015 trial results suggest that these varieties respond similarly to harvesting delays. [11]

For growers, varietal differences in response to harvest delays were only observed for lodging, head loss and grain brightness with varieties responding similarly for the grain receival traits hectolitre weight, screenings and grain protein concentration.

Information from the trials, including 2015 research, is incorporated into the new 2017 Barley variety sowing guide for Western Australia, released by DAFWA and co-funded by the GRDC.

12.4.1 Cost-effective harvest and logistics

Growers need to consider how to avoid the losses arising from wet weather during harvest. Options include increasing the capacity or number of the grower-owned header(s), bringing in contractors, using methods to improve harvesting efficiency (chaser and mother bins) and using on-farm storage.

Key points:

- Machinery costs are driven by scale: the challenge is to keep the capacity of the machine matched to scale (current and anticipated).
- Harvesting costs depend on the header throughput. Doubling header capacity (e.g. with two machines) increases harvesting costs from $16.47/t to $24.40/t (inclusive of chaser bin) with only half the throughput through each of the two machines.
- It is not necessary to double harvesting capacity with two headers to avoid weather damage, but header capacity needs to be enough to get the crop off in reasonable time, so as not to affect other activities.
- Any excess capacity available through having two headers might be used to provide contracting services to neighbours.
- Mother bins are a cost-effective form of short-term, in-paddock storage to provide a buffer between the header and the trucks. Two mother bins might be practical for large (≥3,000 ha) grain-growing operations. Round bins are a cheaper and cost-effective option.
- Grain bags are an alternative means of keeping the grain away from the header during harvest through short-term storage in the paddock.

10 J Curry, B Paynter, A Hills (2016) Response of barley varieties to delays in harvest date. GRDC Grains Research Update, 29 February–1 March 2016, http://www.giwa.org.au/2016researchupdates

11 N Lee (2016) Barley harvest results can help grower decision making. GRDC Media Centre, https://grdc.com.au/Media-Centre/Media-News/West/2016/10/Barley-harvest-results-can-help-grower-decision-making

- With good carriers, it may be unnecessary to own enough trucks to keep up with high-capacity headers. [12]

12.5 Fire prevention

Grain growers must take precautions during the harvest season when operating machinery in extreme fire conditions. Fires are regularly experienced during harvest, in stubble as well as standing crops. The main cause is hot machinery combined with combustible material. This is exacerbated on hot, dry, windy days. Seasonal conditions can also contribute to lower moisture content in grain and therefore a higher risk of fires. [13]

With research showing that 12 harvesters, on average, are burnt to the ground every year in Australia, agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses (Photo 3).

Photo 3: *Keeping headers clean can reduce the risk of fire.*

Source: Rebecca Thyer

Key points:

- Most harvester fires start in the engine or engine bay.
- Fires can be caused by failed bearings, brakes and electricals, and rock strikes.
- Regular removal of flammable material from the engine bay is urged. [14]

12.5.1 Using machinery

To prevent machinery fires, it is imperative that headers, chaser bins, tractors and augers be regularly cleaned, serviced and maintained. Keeping fire-fighting equipment available and maintained is not just common sense—it is a legal requirement.

Take great care when using machiney outdoors:

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12 A. Polkinghorne (2011) Cost effect harvest and logistics. GRDC Update Paper.

13 NSW Rural Fire Service. Farm fire safety. Farm FireWise. NSW Government, http://www.rfs.nsw.gov.au/plan-and-prepare/prepare-your-property/farm-fire-safety

14 N Baxter (2012) A few steps to preventing header fires. GRDC Ground Cover Issue 101, 2 November 2011, http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-101/A-few-steps-to-preventing-header-fires

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GRDC (2016) Cost effective investment in machinery, Fact sheet.

GRDC (2016) Employing seasonal labour for Western Australia's grain industry, Fact sheet.

GRDC (2016) Machinery purchase, Fact sheet.

CBH Group – Growers Harvest Informat/ion

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

- Be extremely careful when using cutters and welders to repair plant equipment, including angle grinders, welders and cutting equipment
- Ensure that machinery components, including brakes and bearings, do not overheat; these components can drop hot metal onto the ground, starting a fire
- Use machinery correctly; incorrect usage can cause it to overheat and ignite
- Be aware that blades of slashers, mowers and similar equipment may hit rocks or metal, causing sparks to ignite dry grass
- Avoid using machinery during inappropriate weather conditions, such as high temperatures, low humidity and windy conditions
- Do maintenance and repairs in a hazard-free, clean working area such as on bare ground or concrete or in a workshop, rather than in the field
- Keep machinery clean and as free from fine debris as possible to reduce risk of on-board ignitions [15]
- Follow local government bans on fires and movement of vehicles

12.6 Prioritising safety

Growers experience intense pressure and fatigue during harvest, and there is usually a higher number of inexperienced seasonal workers employed. Risks can be reduced by growers employing key strategies, such as:

- Make sure all guards on machinery and equipment (harvesters, tractors, chaser bins, silos, field bins and auger), are in place.
- Ensure all people working during harvest – whether employees, contractors or family members – are inducted into the way safety will be managed during the harvest, including fatigue. Expectations for safety should be made very clear to everyone.
- Have a standard policy where all harvester/machinery engines are stopped and keys removed from the ignition during maintenance. Before working under raised hydraulics, header fronts and combs, ensure hydraulic and ram locks have been fitted and that the comb is chocked and supported. Replace all guards after servicing/repairs.
- Make everyone aware of electrical hazards and where they exist on the property. Consider having no-go areas, if practical. [16]

12.7 Receival standards

The minimum protein level acceptable for malt-grade barley is 9%. Malt protein content is reported at 0% moisture (dry), which will be 1–1.5% higher than the 'as-is' basis commonly used for feed grain. In line with malting industry standards, Co-operative Bulk Handling Ltd (CBH) reports all protein figures at 0% moisture basis. Feedlots generally use the 'as-is' figure.

Growers should check receival standards with CBH or their local grain merchant. Updated specifications, and other relevant information, are usually available from September each season. Other purchasers of barley grain may use different specifications. [17]

Most grain purchasers will base their quality requirements on Grain Trade Australia (GTA) standards. For feed barley, grain is required to meet screenings and hectolitre weight specifications. For malting barley, as well as screenings and hectolitre weights, there are requirements for retention (above the 2.5 mm screen) and protein. [18]

15 NSW Rural Fire Service. Farm fire safety. Farm Firewise, NSW Government, http://www.rfs.nsw.gov.au/plan-and-prepare/prepare-your-property/farm-fire-safety

16 S Watt (2016) Prioritising safety this harvest. GRDC Media, 10 October 2016, https://grdc.com.au/Media-Centre/Media-News/National/2016/10/Prioritising-safety-this-harvest

17 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

18 DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

12.8 Harvest weed-seed control

For information on harvest weed seed control, see Section 6.8: Harvest weed seed control.

12.8.1 Intercepting annual weed seed

In WA, high frequencies of herbicide-resistant annual weed populations have been driving farming practices for the last decade and techniques targeting weed seeds during harvest have been widely adopted. At crop harvest, much of the total seed production for the dominant weed species is collected by the harvester (Table 1). Additionally, for some of these species, such as wild radish, high levels of seed are are retained rather than shed over a four week period (Figure 1). Therefore, the collection and management of the weed-seed-bearing chaff fraction can result in significant reductions in population densities of annual weeds.

Table 1: *Proportion of total weed-seed production retained above a low harvest cutting height (15 cm)*

Species	Seed retention above 15 cm (%)
Annual ryegrass	88
Wild radish	99
Brome grass	73
Wild oats	85

Source: AHRI

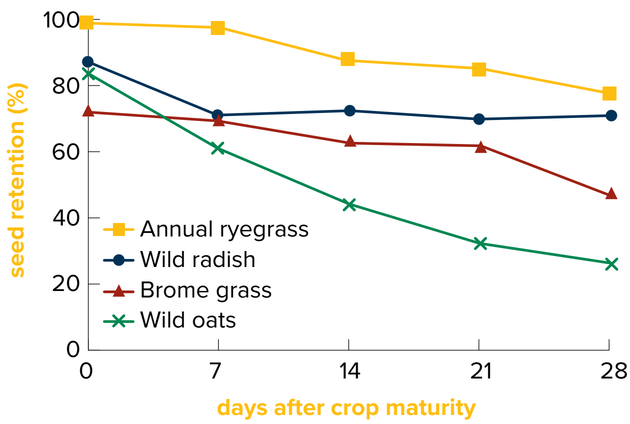


Figure 1: *Seed retention above a harvest height of 15 cm over the first 4 weeks of harvest for the major crop weeds of Western Australian wheat crops.*

Source: AHRI

Lower in-crop weed densities are easier to manage and their potential development as herbicide-resistant populations is dramatically reduced. WA growers have been instrumental in the development of several systems that reduce input of weeds into the seedbank. The adoption of these systems has been critical for the continuation of intensive cropping systems. [19]

MORE INFORMATION

IWM in Australian cropping systems: Section 5. Tactics

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

MORE INFORMATION

GRDC (2014) Narrow windrow burning Driving Agronomy Podcasts.

GRDC (2013) Developments in stubble retention. Report.

IWM Section 5. Tactics

Weed seed bank destruction—windrow chute design

Weed seed bank destruction—header setup and tips for narrow windrowing

Weed seed bank destruction—narrow windrow burning

Weed seed bank destruction—burning windrows safely

Weed seed bank destruction—nutrient Losses: comparing chaff heaps with narrow windrows

Weed seed bank destruction—vary windrow placement to avoid potassium concentration

12.8.2 Burning of narrow windrow

During traditional whole-paddock stubble burning, the very high temperatures needed for weed-seed destruction are not sustained for long enough to kill most weed seeds. By concentrating harvest residues and weed seed into a narrow windrow, fuel load is increased and the period of high temperatures extends to several minutes, improving the kill of weed seeds.

Establishing narrow windrows suitable for autumn burning (Photo 4 and Photo 1) is achieved by attaching chutes to the rear of the harvester to concentrate the straw and chaff residues as they exit. This concentration of residue increases the seed-destruction potential of residue burning. With more fuel in these narrow windrows, the residues burn hotter than standing stubbles or even conventional windrows. Weed-seed kill levels of 99% for both annual ryegrass and wild radish have been recorded from the burning of wheat, canola and lupin stubble windrows. [20]

Windrow burning can work effectively in high yield crops, even above 5 t/ha. Barley crops can be burned successfully, but growers need to do everything correctly. This includes:

- Aim to keep windrows to about 500–600 mm wide
- Make sure chutes direct all chaff and weed seeds into windrow
- Do not over-thresh crops. This leads to rows with little or no air flow, making rows smoulder rather than burn. Rows that smoulder, do get hot enough to kill weed seeds
- Make sure the chute does not restrict air flow from the cleaning fan of the harvester. Most chutes need to open back and front. Closing the front reduces harvest capacity in 4t/ha plus crops
- Try not to run over rows with headers/chaser bins etc., as this crushes the rows. Like over-threshing, it reduces the air flow in burns
- Slow the harvester ground speed at the end of the runs so the sieves empty at the same time as the rotors. This prevents tails of seeds with no straw mixed in that would be difficult to burn

While some types of barley produce good rows it can be tricky not to burn the whole paddock. The low fluffy flag can carry the fire between the rows.

By changing from Gairdner to Hindmarsh⁽ᴰ⁾, which produces a much better straw out of the back of the header, there are fewer issues with flat burning paddocks. This is because the rows are better suited to night-time burning. The bigger windrows aren't smashed, which allows the straw to burn hot enough to kill seeds even when the Fire Danger Index (FDI) is low so that the fire won't spread between rows.

High yielding crops of Scope CL⁽ᴰ⁾ and Buloke⁽ᴰ⁾ can be burned successfully. With barley, the conditions are the most important factor where the humidity needs to be at 75%, the wind <12 km/h and temperature around 12°C. These conditions generally occur between 9pm and 3am. [21]

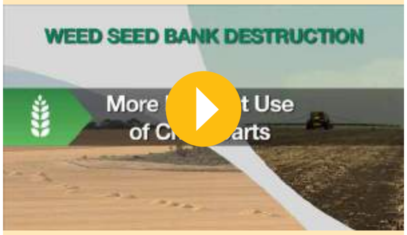
20 M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012

21 D Smith (2015) Burning big crop windrows–it can be done. GRDC Update Papers, 20 August 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Burning-big-crop-windrows-it-can-be-done

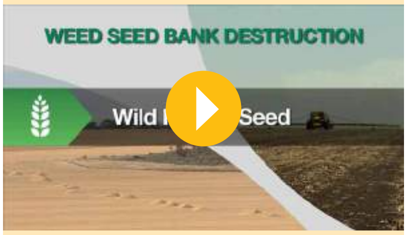
VIDEOS

Weed seed bank destruction—an integrated approach to weed management

Weed seed bank destruction—more efficient use of chaff carts



Weed seed bank destruction—wild radish seed



Weed seed bank destruction—burning chaff dumps

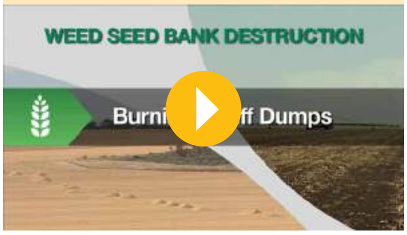


Photo 4: *Harvest in action—producing narrow chaff rows for burning the following autumn.*

Source: A Storrie

Photo 5: *Windrow burning.*

Source: Penny Heuston

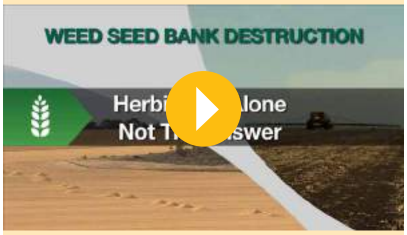
12.8.3 Chaff carts

Chaff carts are towed behind headers during harvest to collect the chaff fraction as it exits the harvester (Photo 6). Collected piles of chaff are then either burnt the following autumn or used as a source of stock feed. [22]

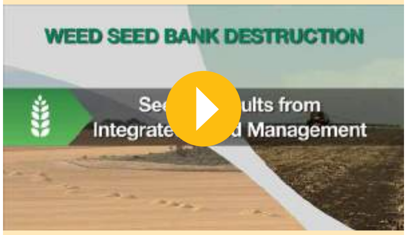
22 GRDC, Section 7: Managing weeds at harvest. GRDC Integrated Weed Management Hub, https://grdc.com.au/resources-and-publications/iwmhub/section-7-managing-weeds-at-harvest

VIDEOS

Weed seed bank destruction—herbicides alone not the answer



Weed seed bank destruction—seeing results from integrated weed management



Over the Fence: Windrow burning beats wild radish

Weed seed bank destruction—seeing results from integrated weed management

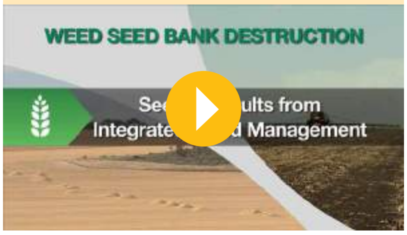


Photo 6: *Chaff cart in action*

Source: Trent Butcher, ConsultAg

The weed-seed collection efficiency of several commercially operating harvesters with attached chaff carts was evaluated by the *Australian Herbicide Resistance Initiative (*AHRI). Harvesters were found to collect 75–85% of annual ryegrass seeds and 85–95% of wild radish seeds entering the front of the header during the harvest operation. Collected chaff must be managed to remove weed seeds from the cropping system. [23]

12.8.4 Bale-direct systems

An alternative to the in-situ burning or grazing of chaff, the bale-direct system uses a large baler attached to the back of the harvester to collect all chaff and straw material as it exits the harvester. As well as removing weed seeds, the baled material has an economic value as a livestock feed source. [24] However, as with all baling systems, consideration must be given to nutrient removal. [25]

The bale-direct system was developed by the Shields family in Wongan Hills as a means of improving straw hay production. It consists of a large square baler directly attached to the harvester that collects and bales all harvest residues. A significant secondary benefit is the collection and removal of annual weed seeds. Studies by AHRI determined that ~95% of annual ryegrass seed entering the harvester was collected in the bales. [26]

For the story of development of header-towed bailing systems, see: http://www.glenvar.com/.

12.8.5 Harrington Seed Destructor

The Harrington Seed Destructor (HSD) is the invention of Ray Harrington, a progressive farmer from Darkan, WA. Developed as a trail-behind unit, the HSD system comprises a chaff-processing cage mill and chaff and straw delivery systems. The retention of all harvest residues in the field reduces the loss and/or banding of nutrients and maintains all organic matter to protect the soil from wind and water erosion, as well as reducing evaporation loss, compared with windrow burning, chaff carts and baling. [27]

Evaluation under commercial harvest conditions by AHRI has determined the HSD process will destroy ≥95% of annual weed seed during harvest. A new version of the HSD, a prototype 'Integrated Harrington Seed Destructor', (iHSD) has been developed by engineers at the University of SA in collaboration with AHRI. [28,29]

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

24 GRDC, Section 7: Managing weeds at harvest. GRDC Integrated Weed Management Hub, https://grdc.com.au/resources-and-publications/iwmhub/section-7-managing-weeds-at-harvest

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

26 M Walsh, S Powles (2007) Management strategies for herbicide-resistant weed populations in Australian dryland crop production systems. Weed Technology 21, 332–338, http://www.jstor.org/stable/4495856?seq=1#page_scan_tab_contents

27 GRDC, Section 7: Managing weeds at harvest. GRDC Integrated Weed Management Hub, https://grdc.com.au/resources-and-publications/iwmhub/section-7-managing-weeds-at-harvest

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

29 AHRI (2013) Weed Destructor integrated into harvester. Australian Herbicide Resistance Initiative, University of Western Australia, http://ahri.uwa.edu.au/weed-destructor-integrated-into-harvester/

MORE INFORMATION

AHRI (2013) Weed Destructor integrated into harvester

IWM Section 5. Tactics

AHRI (2017) Harvest Weed Seed Control Systems are Similarly Effective on Rigid Ryegrass

http://ahri.uwa.edu.au/publications/harvest-weed-seed-control-systems-are-similarly-effective-on-rigid-ryegrass/

GRDC (2010) Managing the weed seedbank. Fact sheet.

GRDC (2014): Harvest systems combined to crush weed-seed resistance. Ground Cover 113.

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

GRDC (2011) Development of the Harrington Seed Destructor.

GRDC (2015) The nuts and bolts of efficient and effective windrow burning.

GRDC (2013) Windrow burning for weed control—WA fad or viable option for the east.

The iHSD comprises of two hydraulically driven cage mills mounted within the rear of the harvester (just below the sieves). AHRI has determined the mills can destroy 93 to 99% of the weed seeds that enter them. [30]

For more information and expressions of interest, go to iHSD.com.

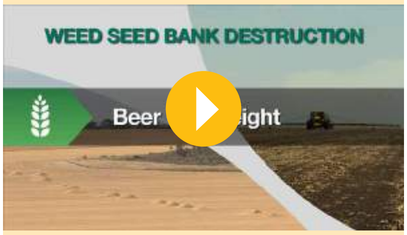
12.8.6 Chaff grinding

Processing of chaff sufficient to destroy any weed seeds that are present during the harvest operation, is the ideal system for large-scale Australian conservation cropping systems. Rendering weed seeds non-viable as they exit the harvester removes the need to collect, handle and/or burn large volumes of chaff and straw residues. The importance and potential industry benefits of this process have meant substantial interest in the development of an effective system.

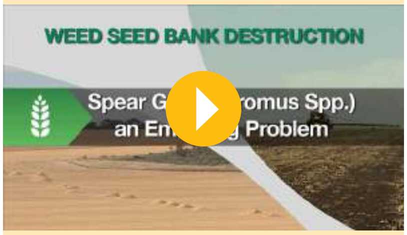
30 AHRI (2016) The integrated Harrington Seed Destructor has arrived. Australian Herbicide Resistance Initiative, University of Western Australia, 8 March 2016, http://ahri.uwa.edu.au/ihsd/

VIDEOS

[Weed seed destruction—beer can height]



[Weed seed bank destruction—Spear grass (Bromus spp.) an emerging problem]



[GCTV1: Integrated weed control & HSD]

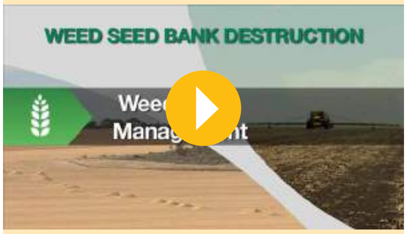
[GCTV10: Harvester mounted weed destructor]

VIDEOS

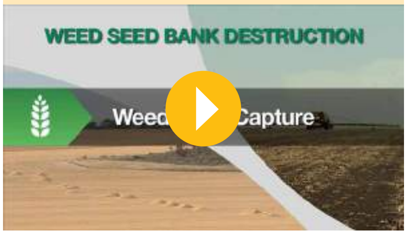
[GRDC Webinar: A beginner's guide to harvest weed seed control]

[GCTV15: Harvest weed seed control]

[Weed seed destruction—weed seed management]



[Weed seed destruction—weed seed capture]



OTHER VIDEOS

[AHRI: Sustaining herbicides with harvest weed seed management]

[DAFWA: Burning windrows for weed control]

[Grassroots Agronomy: NWB Show and Tell video 1: paddock experiences in SNSW]

[Grassroots Agronomy: NWB Show and Tell video 2: chute designs from the growers' perspective]

[WeedSmart: Capture weed seeds at harvest: chaff carts]

[WeedSmart: Capture weed seeds at harvest: Harrington Seed Destructor]

[WeedSmart: Capture weed seeds at harvest: windrow burning]

[WeedSmart: Chaff carts as part of the arsenal]

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

[WeedSmart: Grazing chaff dumps]

[WeedSmart: Narrow windrow burn like a pro]

[WeedSmart: Setting up your header for harvest weed seed control]

Storage

Successful on-farm storage depends on a range of factors. These include storage and handling equipment, capital costs and management used to maintain grain quality, and the control of insects and mould.

Current deregulation of grain markets is now creating a need for more long-term on-farm storage of grain which will eventually enter commercial trade. This allows growers to exploit market opportunities and to apply grain management procedures to maximise crop income. On-farm storage of commercial grain requires large, cheap-per-tonne stores and improved grain management, including pest control. [1]

Established strategies

The best insurance a grower can have is to place extra emphasis on the management of their grain storage facilities. Key strategies include:

- High standard of hygiene for storages and grain handling equipment minimising insect pest breeding sites
- Monthly checks of grain in storage, including planting seed grain, sieving for insects and checking quality
- Aeration fans fitted to storages, operated by an automatic controller
- Grain temperatures–checked and achieving 20–23°C in summer and less than 15°C in winter
- Fumigations, when required, are carried out in sealable silos. These silos are pressure tested at least once a year
- Storage record keeping–a simple system to record details such as grain variety, moisture content, treatments, inspections dates, and data for insects and grain temperature [2]

13.1 How to store barley on-farm

13.1.1 Malt barley

Keeping malting barley alive and respiring is vital for the malting process. Only a live barley grain will trigger the stream of biochemical reactions required to convert barley into malt suitable for brewing. It is important barley growers understand the need to store barley correctly to maintain germinative capacity and vigour, so it can be effectively processed into malt. [3]

Special consideration should be given to storing malt barley. Storage conditions largely determine the rate at which quality parameters of Australian barley varieties change after harvest. Initial kernel condition, temperature, moisture content and storage time are major factors influencing changes in malting quality.

Barley is typically harvested and initially stored at moderate temperatures (25–30°C). Depending on storage conditions, Australian malting barley can take several months to reach optimum malting quality while dormancy and water sensitivity are broken down.

Manipulating storage conditions can provide maltsters with homogeneous barley to malt. Research has identified several options for managing barley dormancy to provide opportunities to malt and export barley earlier, such as the use of agricultural chemicals or application of dry heat.

1 Stored Grain Information Hub (2016) Select grain stores carefully to control costs. http://storedgrain.com.au/select-grain-stores-carefully-to-control-costs/

2 P Burrill (2013) Grain storage future pest control options and storage systems 2013–2014. GRDC Update Papers, July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

3 Barley Australia (2007) Germination a must for malting barley. http://www.seednet.com.au/documents/MEDIA_RELEASE_sausage_bags_June_2007.pdf

MORE INFORMATION

GRDC (2013) Economics of on-farm grain storage: A Grains Industry Guide.

GRDC (2015) National grain storage extension project. Ground Cover Issue 119.

GRDC-funded CSIRO research shows understanding and carefully manipulating the storage process, post-harvest dormancy can be removed without compromising barley quality. [4]

Delaying aeration cooling for a short period, or raising the grain temperature using aeration fans during the warmer part of the day followed by rapid cooling after dormancy has been removed, can effectively accelerate the maturation of barley. [5]

Mould

The key element of a successful commercial on-farm grain storage system is safekeeping grain against insect and mould damage. This is particularly important in Australia where wheat and barley are taken into storage at high grain temperatures and where long, hot summers and short, mild winters favour insect development. During recent years, some growers who invested significant capital in on-farm storage have turned away from their investment because of difficulties in maintaining grain from insect attack and moulding.

The best way to protect grain against mould development is to dry it to moisture levels below which mould spores can develop before it is transferred into storage.

If the grain moisture content exceeds certain critical values, the spores of specific fungal species will start developing. These critical moisture values often occur at increments as small as 0.5% and therefore accurate and dependable moisture measurement is important. Moulds develop at a fast rate if grain temperature is high, but the key factor is grain moisture content. Safe moisture content for barley is 12.5% or less. [6]

13.2 Storage option

Short-term storage options (bunkers, bags and sheds) are suited to cereals, which can be moved without damage and if permitted have protectants applied at time of in-loading. For growers planning to store grains that cannot have protectants applied or are to be stored for more than 3 months, then gas-tight, aeratable silos are the best option. [7]

13.2.1 Silos

According to the Kondinin Group National Agricultural Survey 2011, silos account for 79% of Australia's on-farm grain storage, compared with 12% bunkers and pits, and 9% grain bags.

Aerated silos that can be sealed during fumigation are widely acknowledged as the most effective way to store grain on-farm (Table 1). An Australian standard (AS2628) is now available for sealable silos that manufacturers in Australia can choose to use as a construction standard to ensure reliable fumigation results.

4 CSIRO and Barrett Burston Malting Co. (2003) The effect of storage conditions on post-harvest maturation and maltability of barley. E-Malt, http://www.e-malt.com/statistics/ScientificDigest/BTSbarleyStorage.pdf

5 CSIRO (2011) Stored barley manipulated to brew better beer. CSIRO Food and Agriculture June 2010, Updated October 2011.

6 Stored Grain Information Hub (2016) Select grain stores carefully to control costs. http://storedgrain.com.au/select-grain-stores-carefully-to-control-costs/

7 GRDC (2016) On-farm storage needs careful calculation. Ground Cover Issue 125. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-125-NovemberDecember-2016/On-farm-storage-needs-careful-calculation

Table 1: *Advantages and disadvantages of grain storage options*

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	• Allows phosphine and controlled atmosphere options to control insects • Easily aerated with fans • Fabricated on-site or off-site and transported • Capacity 15–3,000 t • ~25-year service life or more • Simple in-loading and out-loading • Easily administered hygiene (cone base particularly) • Can be used multiple times in a season	• Requires foundation to be constructed • Relatively high initial investment required • Seals must be regularly maintained • Access requires safety equipment and infrastructure • Requires an annual test to check gas-tight sealing
Non-sealed silo	• Easily aerated with fans • 7–10% cheaper than sealed silos • Capacity 15–3,000 t • ~25-year service life, or more • Can be used multiple times in a season	• Requires foundation to be constructed • Silo cannot be used for fumigation—see phosphine label • Insect-control options limited to protectants in eastern states and dryacide in WA • Access requires safety equipment and infrastructure
Grain storage bags	• Low initial cost • Can be laid on a prepared pad in the paddock • Provide harvest logistics support • Can provide segregation options • All ground-operated • Can accommodate high-yielding seasons	• Requires purchase or lease of loader and unloader • Increased risk of damage beyond short-term storage (typically 3 months) • Limited insect-control options, fumigation only possible under specific protocols • Requires regular inspection and maintenance, which needs to be budgeted for • Aeration of grain in bags currently limited to research trials only • Must be fenced off • Prone to attack by mice, birds, foxes, etc. • Limited wet-weather access if stored in paddock • Single-use only • Need to dispose of bag after use
Grain storage sheds	• Can be dual-purpose • 30-year service life, or more • Low cost per stored tonne	• Aeration systems require specific design • Risk of contamination from dual-purpose use • Difficult to seal for fumigation • Vermin control difficult • Limited insect control options without sealing • Difficult to unload

Growers should pressure-test sealable silos once a year to check for damaged seals on openings. Storages must be sealed properly to ensure that high concentrations of phosphine gas are held long enough to give an effective fumigation.

At an industry level, it is in growers' best interests to fumigate only in gas-tight sealable storages to help stem the rise of insect resistance to phosphine. This resistance has come about because of the prevalence of storages that are poorly sealed or unsealed during fumigation. [8]

13.2.2 Bunkers and shed storage

Other grain store types currently available for on-farm use include bunkers and sheds. Included in this category are steel mesh structures lined with plastic sheeting. Large bunkers (20–30 kt) provide cost-effective grain stores but the cost per tonne of storage capacity increases significantly as the bunker size decreases. The need to replace the plastic sheeting every few years to maintain a weatherproof seal significantly increases the capital cost of the structure over time.

Bunkers consisting of plastic sheeting can be beneficial fumigation enclosures for grain safekeeping. The main advantage of bunkers is most of the capital outlay is spread over its period of use. Small sheds, which can be gastight sealed for successful fumigation with phosphine are also available for on-farm grain storage.

These sheds are based on hybrid technology with bolted corrugated steel silos. Shipping containers, which can be bought or rented, can also be used. A 6.15 m container can accommodate about 27 t of grain and can be fitted with a polyethylene liner to improve its gas tightness for fumigation.

Grain handling equipment for on-farm in-loading and out-loading from small bunkers, sheds and shipping containers currently rely on mobile augers, which can be difficult to use. [9]

13.2.3 Grain bags

Due to their short-term storage capacity and suitability for supporting harvest pressure, growers tend to use grain bags primarily for extending existing storage during high-yielding seasons, typically for wheat and barley. Aeration cooling is not yet proven with grain bags.

Cereal grain quality is best preserved when the moisture content is below 12.5%. Storing grain of a higher moisture content in bags not only compromises grain quality but increases the risk of grain swelling and splitting the bag.

Being unable to aerate bags and having a large surface area exposed to heating from the sun means grain remains warm for months after harvest. This can affect seed germination rates and malt barley quality. Storing grain at harvest temperatures of 30°C and above favours high insect reproduction rates, so take extra care with hygiene and monitoring. Bulk grain bags are an effective form of storage when used in the right situations and when they are managed correctly. [10]

13.2.4 Grain storage costs

When making a decision about installing on-farm grain storage facilities, consider the following costs:

- The cost of fixed assets, for example, the capital costs of the storage structure, grain handling equipment and grain safekeeping equipment. Included in this are delivery, construction and installation costs to provide a fully operational facility

8 C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide. GRDC, https://grdc.com.au/__data/assets/pdf_file/0025/206791/fumigating-with-phosphine.pdf.pdf

9 Stored Grain Information Hub (2016) Select grain stores carefully to control costs. http://storedgrain.com.au/select-grain-stores-carefully-to-control-costs/

10 GRDC (2014) Successful storage in grain bags. Fact sheet, July 2014, http://storedgrain.com.au/wp-content/uploads/2014/09/GSFS-6_GrainBags-July14.pdf

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GRDC (2013) Grain storage: Silo buyer's guide. Fact sheet.

GRDC (2012) Performance testing aeration systems. Fact sheet.

GRDC (2011) Fumigating with phosphine, other fumigants and controlled atmospheres.

- The cost of owning the facility, which includes maintenance, depreciation on capital equipment, insurance and opportunity cost of interest on money invested in the facility
- The opportunity costs, which include interest on the value of the grain in storage and insurance
- Grain management and husbandry costs, including storage losses, drying costs, electricity costs for grain handling, pest control costs and labour [11]

Detailed information about selecting, siting and fitting out silos, grain storage bags, sheds and bunkers is contained in the GRDC Grains Industry Guide Grain storage facilities: Planning for efficiency and quality.

13.3 Aeration during storage

Aeration of stored barley is the key non-chemical tool used to minimise the risk of insect infestations and spoiling through heat and/or moisture damage (Photo 1). [12]

Photo 1: *Storage with aeration is important for protecting Australia's markets.*

Source: DAF Qld

Grain aeration systems are generally designed to carry out either a drying or cooling function—not both. Aeration cooling can be achieved with airflow rates of 2–3 L/s/t delivered from fans driven by a 0.37 kilowatt (0.5 horsepower) electric motor while aeration drying can be achieved with fans delivering 15–25 L/s/t, typically powered by 7kW (10hp) electric motors. Low-capacity fans cannot push this drying front through the grain fast enough to dry grain in the top section of a stack before it turns mouldy. The risk of using high capacity fans for cooling is they increase grain moisture very quickly if run when ambient conditions are above 85% relative humidity. If a storage is only fitted with high capacity aeration drying fans, options for aeration cooling include; reducing fan run time, fitting a smaller fan for cooling, restricting the drying fan inlet to reduce its capacity or installing a variable speed drive to reduce fan speed. [13]

11 Stored Grain Information Hub (2016) Select grain stores carefully to control costs. http://storedgrain.com.au/select-grain-stores-carefully-to-control-costs/

12 GRDC (2012) Performance testing aeration systems. GRDC Grain Storage Fact sheet, August 2012, http://www.grdc.com.au/Resources/Factsheets/2012/08/Grain-Storage-Performance-testing-aeration-systems

13 GRDC (2013) Aerating Stored Grain: Cooling or Drying for Quality Control. A Grains Industry Guide, https://grdc.com.au/Resources/Bookshop/2013/06/Aerating-stored-grain

Choices

Knowing whether grain needs to be dried or cooled can be confusing, but there are some simple rules to follow:

- Grain that is dry enough to meet specifications for sale (12.5 %) can be cooled, without drying, to slow insect development and maintain quality during storage
- Grain of moderate moisture (up to 15%) will require aeration drying to reduce the moisture content to maintain quality during storage
- If aeration drying is not available immediately, moderately moist grain can be cooled for a short period to slow mould and insect development, then dried when the right equipment is available
- After drying to the required moisture content, cool the grain to maintain quality
- High-moisture grain (for example, 16% and higher) will require immediate moisture reduction before cooling for maintenance [14]

Aeration typically reduces stored grain temperatures by more than 10°C during summer (Figure 1), which significantly reduces the threat of a serious insect infestation. [15]

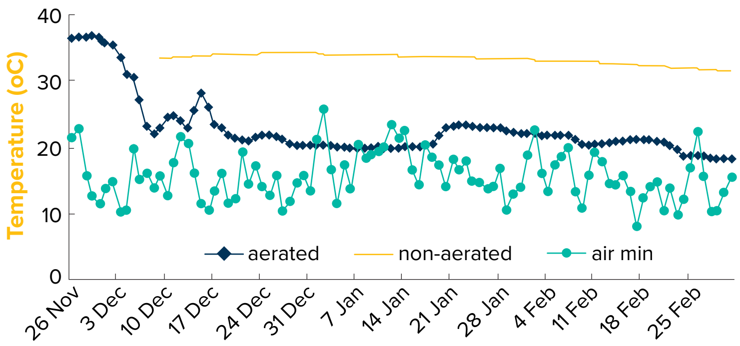

Figure 1: *Comparison of wheat grain temperatures in aerated and non-aerated silos.*

Source: Qld DAF

13.3.1 Aeration cooling

The aim of aeration cooling is to maintain grain quality during storage. By lowering grain temperature and creating uniformity through the grain stack, mould is less likely to develop. Lower temperatures are also less attractive for insects, conditions can slow (and even stop) insect development and seed viability is preserved.

Without aeration cooling, grain put into storage at warm harvest temperatures will hold these temperatures for a long time, in most cases taking months to cool down on its own.

Aeration cooling moves the air pockets around the grain, which evens out any hot or moist areas, creating a uniform stack. This prevents hot spots forming, which are ideal locations for mould and insects to develop and spread through the storage. [16]

14 GRDC (2013) Aerating Stored Grain: Cooling or Drying for Quality Control. A Grains Industry Guide, https://grdc.com.au/Resources/Bookshop/2013/06/Aerating-stored-grain

15 P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014. GRDC Update Papers, 18 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

16 GRDC (2013) Aerating Stored Grain: Cooling or Drying for Quality Control. A Grains Industry Guide, https://grdc.com.au/Resources/Bookshop/2013/06/Aerating-stored-grain

13.3.2 Aeration drying

Aeration drying requires a specifically designed system and is a much slower process than aeration cooling. In rare situations aeration cooling fans can reduce grain moisture slightly, but they cannot reliably reduce grain moisture to a safe level. In fact this 'drying' effect is likely to be simply a redistribution of moisture within the grain stack. Much higher airflow rates are required for aeration drying in order to push a drying front through the grain bulk.

Aeration drying relies on a high volume of air passing through the grain to slowly remove moisture. It is usually done in a silo with either high-capacity aeration fans, only partly filled with grain or a purpose-built drying silo. Aeration drying depends on warm, dry weather conditions. It is important to seek reliable advice on equipment requirements and correct management of fan run times, otherwise there is a high risk of reducing grain quality.

There are four key components to enable successful aeration drying:

- airflow rates of 15–25 L/s/t
- well-designed ducting for even airflow through the grain
- exhaust vents in the silo roof
- dry weather conditions. [17]

High moisture grain

Research shows cereals at 12% moisture content stored for 6 months at 30–35°C (unaerated grain temperature) will have reduced germination percentage and seedling vigour.

A national upper limit for moisture of 12.5% applies to barley at receival, but deliveries are usually in the range 10.5–11%. [18]

Special measures must be taken to minimise the risk of insect infestations or heat damage if the crop is harvested in damp conditions. [19]

Table 2: *The effect of grain temperature on insects and mould*

Grain temperature (°C)	Insect and mould development	Grain moisture content (%)
40–55	Seed damage occurs, reducing viability	
30–40	Mould and insects are prolific	>18
25–30	Mould and insects active	13-18
20–25	Mould development is limited	10-13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group

17 GRDC (2013) Aerating Stored Grain: Cooling or Drying for Quality Control. A Grains Industry Guide, https://grdc.com.au/Resources/Bookshop/2013/06/Aerating-stored-grain

18 Wheat Quality Objectives Group (2009) Understanding Australian wheat quality. GRDC, https://grdc.com.au/__data/assets/pdf_file/0011/202421/grdcwheatquality.pdf.pdf

19 GRDC (2013) Dealing with high-moisture grain. GRDC Grain Storage Fact sheet, June 2013, https://grdc.com.au/__data/assets/pdf_file/0024/152385/gsfs-7_highmoisturegrain_2013_lr_final-pdf.pdf.pdf

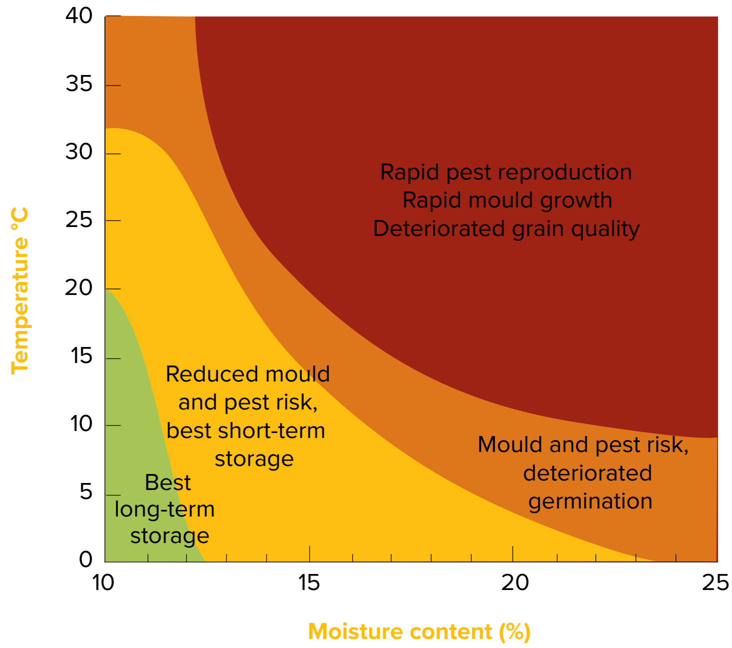

Figure 2: *Effects of temperature and moisture on stored grain.*

Source: CSIRO Ecosystems sciences as published in Grain Storage Fact Sheet—dealing with high-moisture grain

Blending

Blending is the principle of mixing slightly over-moist grain with lower-moisture grain to achieve an average below the ideal 12.5% moisture content. Using grain with a moisture content level up to 13.5%, blending can be an inexpensive way of dealing with wet grain, providing the infrastructure is available. If aeration is not available, blending must be evenly distributed, although aeration cooling does allow blending in layers.

If use of a grain dryer is not an option, grain that is over the standard safe-storage moisture content of 12% and up to the moderate moisture level of 15% can be managed by aerating until drying equipment is available. Blending with low-moisture grain and aerating is also a commonly used strategy (Figure 3).

MORE INFORMATION

GRDC (2016) Using aeration cooling for stored grain in Western Australia.

GRDC (2015) Solar-powered aeration cooling shows promise. Ground Cover Issue 119.

GRDC (2013) Aerating stored grain, cooling or drying for quality control. A Grains Industry Guide.

GRDC (2012) Performance testing aeration systems. Fact sheet.

GRDC (2013) Dealing with high-moisture grain. Fact sheet.

For general information on handling, drying and cooling see: Agridry Rimik Pty Ltd

https://www.agric.wa.gov.au/pest-insects/insect-pests-stored-grain?page=0%2C1

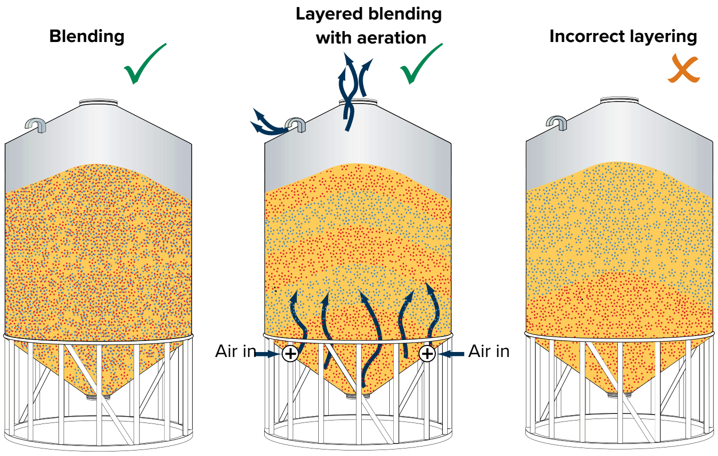

Figure 3: *Correct blending.*

Source: Kondinin Group

13.4 Hygiene

Effective grain hygiene and aeration cooling can overcome 75% of pest problems in stored grain. All grain residues should be cleaned out when silos and grain-handling equipment are not in use to help minimise the establishment and build-up of pest populations.

In one year, a bag of infested grain can produce more than one million insects, which can walk and fly to other grain storages where they will start new infestations. Meticulous grain hygiene involves removing any grain residues that can harbour pests and allow them to breed.

Grain pests live in protected, sheltered areas in grain-handling equipment and storage, and they breed best in warm conditions. Insects will also breed in outside dumps of unwanted grain (Photo 2). Try to bury grain or spread unwanted grain out to a shallow depth of <20 mm so insects are exposed to daily temperature extremes and other insect predators. [20]

20 GRDC (2013) Hygiene and structural treatments for grain storages. Fact sheet, June 2016, https://grdc.com.au/Resources/Factsheets/2013/06/Grain-Storage-Fact-Sheet-Hygiene-and-structural-treatments-for-grain-storages

Photo 2: *Poor grain hygiene undermines effective stored grain insect control.*

Source: DAF Qld

Grain insect pests may be divided into primary and secondary pests (Photo 3). Primary grain insects have the ability to attack whole, unbroken grains, while secondary pests attack only damaged grain, dust and milled products. [21]

Photo 3: *A primary grain pest, the lesser grain borer Rhyzopertha dominica is the most serious pest of stored grain in WA.*

Source: DAF Qld

Successful grain hygiene involves cleaning all areas where grain residues becomes trapped in storages and equipment. Grain pests can survive in a tiny amount of

21 DAFWA (2016) Insect pests of stored grain. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1167

MORE INFORMATION

GRDC (2015) Starving Grain Bugs. Driving Agronomy Podcasts.

GRDC (2013) Hygiene and structural treatments for grain storage Fact sheet.

GRDC (2013) Western Region Stored grain pests – identification. Fact sheet.

GRDC (2013) Grain Storage Pest Control Guide Western Region. Fact sheet.

GRDC Grain silo hygiene Ground Cover TV2.

grain, which can go on to infest freshly harvested clean grain. Harvesters and grain-handling equipment should be cleaned out thoroughly with compressed air after use.

After grain storages and handling equipment are cleaned, they should be treated with a structural treatment. Diatomaceous earth (DE) is an amorphous silica also commonly known as the commercial product Dryacide™ and is widely used for this purpose. It acts by absorbing the insect's cuticle or protective waxy exterior, causing death by desiccation. If applied correctly with good coverage in a dry environment, DE can provide up to 12 months' protection by killing most species of grain insects and with no known risk of resistance. It can be applied as a dry dust or slurry spray.

Although many cereal grain buyers accept the use of approved chemical insecticide structural treatments to storages, growers should avoid using them, or wash the storage out, before storing oilseeds and pulses. Several export and domestic markets require 'pesticide residue free' grain (PRF), and growers are advised to check with potential grain buyers before using grain protectants or structural treatments. [22]

Grain Trade Australia (GTA) stipulates standards for heat-damaged, bin-burnt, storage-mould-affected or rotten barley, all of which can result in the discounting or rejection of grain. GTA has nil tolerance to live, stored grain insects. [23]

Stored grain insects include: Rust-red flour beetle, Confused flour beetle, Saw-toothed grain beetle, Flat grain beetle, Warehouse moth, Indian meal moth and Warehouse beetle.

The lesser grain borer and rust-red flour beetle are some of the most common insect pests found in stored cereals. Other common species to watch for include weevils (*Sitophilus* spp.), sawtoothed grain beetle (*Oryzaephilus* spp.), flat grain beetles and rusty grain beetle (*Cryptolestes* spp.), psocids (booklice), Indian meal moth (*Plodia interpunctella*) and angoumois grain moth (*Sitotroga cerealella*). Another dozen or so beetles and mites, are sometimes present as pests in stored cereal grain.

Photographs and descriptions of stored grain pests can be found in the GRDC Stored grain pests identification. The Back Pocket Guide.

13.5 Grain protectants and fumigants

Grain Trade Australia is aware of cases where various chemicals have been used to treat stored grain that are not approved for grain or that particular grain type. When they are detected, an entire shipload can be rejected, often with serious long-term consequences for important Australian grain markets.

Accessing markets that require pesticide residue free (PRF) grain does not rule out the use of some fumigants, including phosphine (Photo 4). However, PRF grain should not have any chemical residues from treatments that are applied directly to the grain as grain protectants. Before using a fumigant, growers need to check with prospective buyers, because the use of some chemicals may exclude grain from certain markets. [24]

22 GRDC (2013) Hygiene and structural treatments for grain storages. Grain Storage Fact sheet, June 2013, https://grdc.com.au/Resources/Factsheets/2013/06/Grain-Storage-Fact-Sheet-Hygiene-and-structural-treatments-for-grain-storages

23 GTA (2013) Barley Trading Standards, 2015–16 season. Grain Trade Australia, August 2015, http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/2015_2016/Section%2002%20-%20Barley%20Trading%20Standards%20201516%20Final.pdf

24 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry. Cooperative Research Centre for National Plant Biosecurity Technical Report, http://www.graintrade.org.au/sites/default/files/file/NWPGP/Phosphine%20Resistance%20Strategy.pdf

Photo 4: *Phosphine is widely accepted as having no residue issues.*

Source: DAF Qld

13.5.1 Pesticide residues

Pesticide residues in barley grain or dye from foam markers on barley grain can degrade the value of the premium product and seriously reduce its acceptability in local and overseas markets. Label rates, times of application and withholding periods are specified on all pesticide labels and have been set so that the Maximum Residue Levels (MRLs) are not exceeded.

Harvesting crops before the withholding period has expired or using product at rates above the labelled rate can leave unacceptable residues in the crop. To reduce the chance of unacceptable residues, it is up to the grower to select treatments that can be safely used. Good crop monitoring is needed to ensure problems which may require treatment before harvest are carried out within the harvest withholding periods.

Countries importing Australian barley are becoming more vigilant in their testing for chemical residues for food safety requirements and anything that may affect the processing quality. Importing countries who detect unacceptable residues will reject or down grade the shipment and increase their testing requirements. Further detection may result in a ban of Australian grain in that marketplace.

Observe the withholding periods and use the rate specified within the label limits to minimise any problems. [25]

13.5.2 Phosphine

Although phosphine has resistance issues, it is widely accepted as having no residue issues. The grains industry has adopted a voluntary strategy to manage the build-up of phosphine resistance in pests. Its core recommendations are to limit the number of conventional phosphine fumigations on undisturbed grain to three per year and to employ a break strategy. The break is provided by moving the grain to eliminate

25 J Russell, B Paynter, J Holmes (2008) Department of Agriculture and Food, Western Australia, Farmnote:325. Barley grain quality – pesticide residues and foam marker dye staining. https://www.researchgate.net/publication/274077755_Barley_grain_quality_-_pesticide_residues_and_foam_marker_dye_staining

pockets where the fumigant may fail to penetrate, and by retreating it with an alternative disinfestant or protectant. [26]

Effective phosphine fumigation can be achieved by placing the chemical at the rate directed on the label onto a tray and hanging it in the top of a pressure-tested, sealable silo. A ground-level application system is also an efficient application method, and these can be combined with a silo recirculation system on larger silos to improve the speed of gas distribution. After fumigation, grain should be ventilated for a minimum of 1 day with aeration fans running, or 5 days if no fans are fitted. A minimum withholding period of 2 days is required after ventilation before grain can be used for human consumption or stock feed. The total time required for fumigating ranges from 7 to 20 days depending on grain temperature and the storage structure.

Sealable silos

The Kondinin Group National Agricultural Survey 2009 revealed 85% of respondents had used phosphine at least once during the previous 5 years and, of those users, 37% used phosphine every year for the past 5 years. A GRDC survey during 2010 revealed only 36% of growers using phosphine applied it correctly—in a gas-tight, sealable silo.

Research shows fumigating in a storage that is not gas-tight does not achieve a sufficient concentration of fumigant for long enough to kill pests at all life-cycle stages. For effective phosphine fumigation, a minimum gas concentration of 300 parts per million (ppm) for 7 days or 200 ppm for 10 days is required (Figure 4). Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks (Figure 5). The rest of the silo also suffers from reduced gas levels. [27]

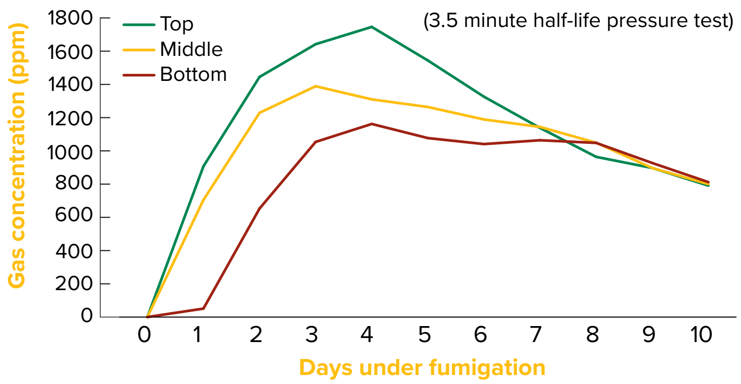

Figure 4: *Gas concentration in gas-tight silo.*

Source: DAF Qld

26 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry. Cooperative Research Centre for National Plant Biosecurity Technical Report, http://www.graintrade.org.au/sites/default/files/file/NWPGP/Phosphine%20Resistance%20Strategy.pdf

27 GRDC (2010) Pressure testing sealable silos. GRDC Grain Storage Fact sheet, September 2010, http://storedgrain.com.au/pressure-testing/

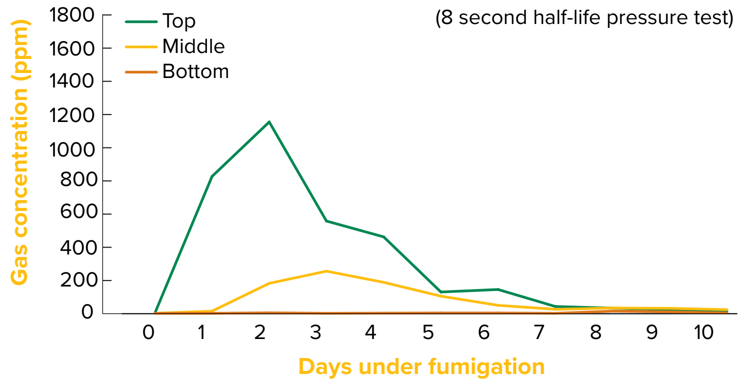

Figure 5: *Gas concentration in a non-gas-tight silo.*

Source: DAF Qld

Silo Bags

Silo bags as well as silos can be fumigated (Photo 5). Research conducted by storage specialists and growers in QLD found sufficient concentrations of phosphine can be maintained for the required time to fumigate grain successfully in a silo bag. Trials on a typical, 75-m-long bag containing approximately 240 t of grain successfully controlled all life stages of the lesser grain borer.

Photo 5: *Silo bags can also be fumigated.*

Source: DAF Qld

When using phosphine in silos or silo bags, it is illegal to mix phosphine tablets directly with grain because of tablet-residue issues. Trays in silo bags are not practical, therefore tablets are placed in a perforated conduit to contain tablets and spent dust. The 1-m tubes are speared horizontally into the silo bag and removed at the end of the fumigation. Trial results suggest that the spears should be no more than 7 m apart and fumigation should occur over 12–14 days (Figure 6). In previous trials, when spears were spaced 12 m apart, the phosphine gas took too long to diffuse throughout the whole bag. [28]

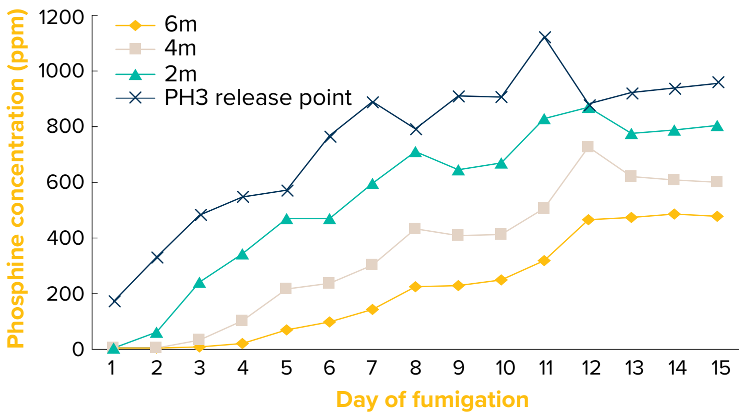

Figure 6: *Spread of phosphine gas in a silo bag from a release point to gas-monitoring lines at 2, 4 and 6 m along a silo bag.*

MORE INFORMATION

GRDC Grain bags–fumigation. Ground Cover TV.

GRDC (2011) Fumigating with phosphine, other fumigants and controlled atmospheres. Grains Industry Guide.

13.5.3 Alternative strategies

While phosphine is still the most commonly-used gas fumigant for controlling pests in stored grain, there are other options. Each of the alternatives still requires a gas-tight, sealable silo and are currently more expensive than using phosphine, but they offer an alternative for resistant pest species. Nitrogen (N) and carbon dioxide (CO_2) carry the added advantage of being nonchemical control alternatives. Both N and CO_2 methods of control are sometimes referred to as controlled atmosphere (CA) because they change the balance of natural atmospheric gases to produce a toxic atmosphere.

Carbon dioxide

Treatment with CO_2 involves displacing the air inside a gas-tight silo with a concentration level of CO_2 high enough to be toxic to grain pests. This requires a gas-tight seal, measured by a half-life pressure-test of no less than five minutes. To achieve a complete kill of all the main grain pests at all life stages, CO_2 must be retained at a minimum concentration of 35% for 15 days. This method of fumigation is not recommended when temperatures are below 15°C. At temperatures below 20°C CO_2 is less effective because insects are less active so the concentration must be maintained for an extended period.

Nitrogen

Grain stored under N provides insect control and quality preservation without chemicals. It is safe to use, environmentally acceptable and the main operating cost is electricity. It also produces no residues so grains can be traded at any time, unlike chemical fumigants that have withholding periods. Insect control with nitrogen involves a process using Pressure Swinging Adsorption (PSA) technology, modifying the atmosphere within the grain storage to remove everything except N, starving the pests of oxygen.

The application technique is to purge the silo by blowing N-rich air into the base of the silo, forcing the existing, oxygen-rich atmosphere out the top. PSA takes several hours of operation to generate 99.5% pure N and before the exhaust air has a reduced concentration of 2% oxygen. At 2% oxygen adult insects cannot survive,

28 P Burrill, A Ridley (2012) Silo bag fumigation. GRDC Grains Research Update, Northern Region, Issue 66,

providing this concentration is maintained for 21 days with a grain temperature above 25°C. Anything less will not control all life stages —eggs, larvae and pupae. For grain below 25°C this period is extended to 28 days. The silo must be checked the day after fumigation and may need further purging to remove oxygen that has diffused from the grain.

Nitrogen storage will also maintain the quality of canola and pulses by inhibiting the respiration process that causes oxidation, which leads to seed deterioration, increased free fatty acids and loss of colour. [29]

It's all in the seal

Replacing oxygen in grain storage silos with nitrogen has proven an effective way to remove insects at all stages of their life cycle, leaving stored grain—be it wheat or canola—preserved, residue-free and subject to no withholding periods.

Nitrogen is also the preferred storage option, says Western Australia grower Doug Clarke, who is the earliest adopter of the technology in its on-farm form.

Mr Clarke made the switch several years ago on his Lake Grace property, and has made his silos available to Murdoch University researchers led by stored-grain expert Professor YongLin Ren, with support from the GRDC.

Mr Clarke has hosted visitors over the years, including overseas buyers, and says he has learnt the extent to which insecticide-free grain is preferred by buyers.

While he says the system is performing well, he is committed to continuous improvement.

However, one challenge is that there is currently no price signal favouring residue-free grain to compensate for the investment and the extra work associated with nitrogen-based storage.

In relation to the technology itself, Mr Clarke has no issue with existing oxygen-purging systems. He says the nitrogen generator needed to purify nitrogen from the atmosphere and pump it into a silo is a machine developed by the oil industry, which is widely available.

"At a rate of 30 cubic metres an hour, it costs about $5 worth of diesel to purge a silo of oxygen all the way down to 0.05 per cent total content," he says. "Best of all, insects never acquire resistance."

Another challenge relates to infrastructure: silos leaking.

"The standards for sealed silos are too low for nitrogen storage of grain," Mr Clarke explains. "The accepted level on the seals for a silo is the loss of half an inch (12.7 millimetres) of water pressure in three minutes."

The oxygen in the silo needs to be purged long enough to kill all insects. Mr Clarke has identified a relationship between eradication time (for all stages in an insect's life cycle) under nitrogen and grain temperature.

The eradication time is as low as one week at high temperatures, at 20°C it blows out to three weeks, and below that temperature he says it does not work.

29 C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide. GRDC Stored Grain Project, January 2011, https://grdc.com.au/__data/assets/pdf_file/0025/206791/fumigating-with-phosphine.pdf.pdf

It is these circumstances that have created resistance to insecticides and an interest in the latest sealing technology.

"What I am saying is that the better the seal, the better control you have under any fumigant. We need to be looking to the latest sealing technology, including polymers and 3D printers," he says. "The area that now needs improving is the silo manufacturing." [30]

Sulfuryl fluoride

According to research, sulfuryl fluoride (SF) has excellent potential as an alternative fumigant to control phosphine-resistant grain storage pests (Table 2). It is currently registered in Australia as a grain disinfestant. Supplied under the trade name 'ProFume®', SF can be used only by a licensed fumigator.Annual resistance-monitoring data were analysed to assess the impact of SF as an alternative fumigant to phosphine. This revealed that after the introduction of SF in central storages across the northern and southern grain regions in 2010, there was a 50% reduction in the incidence of strongly phosphine-resistant populations of rusty grain beetle at the end of the first year, and the downward trend is continuing. Complementary laboratory experiments have shown that phosphine resistance does not show cross-resistance to SF, which is an additional advantage of using SF. [31]

VaporMate®

VaporMate® (active ingredient ethyl formate 166.7 g/kg) is approved for use in stored cereals and oilseeds. It is registered to control all life stages of the major storage pest insects—lesser grain borer, rust-red flour beetle (*Tribolium* spp.), sawtoothed beetle, flat grain beetles, storage moths and psocids (booklice). However, it does not fully control all stages of rice weevil. It must only be used by a licensed fumigator.

Protectants

Two grain protectants are now available became available in 2013:

- K-Obiol (active ingredients deltamethrin 50 g/L, piperonyl butoxide 400 g/L). Features acceptable efficacy against the common storage pest, lesser grain borer, which has developed widespread resistance to current insecticides. Insect-resistance surveys in the past consistently detected low levels of deltamethrin-resistant insect strains in the industry. Therefore resistant populations could increase quickly with widespread excessive use of one product. A product stewardship program has been developed to ensure correct use of the product.
- Conserve On-Farm (active ingredients (chlorpyrifos-methyl 550 g/L, S-methoprene 30 g/L, spinosad 120 g/L) to control most major insect pests of stored grain, including the resistant lesser grain borer. Maximum residue limits have been established with key trading partners and there are no issues with meat residue bioaccumulation. [32]

MORE INFORMATION

GRDC (2014) Grain Fumigation Guide. Fact sheet.

GRDC (2011) Stay safe around grain storage. Fact sheet.

APVMA: Metal phosphides—priority 5

30 G Braidotti (2015) It's all in the seal. GRDC Ground Cover, Issue 119, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-119--Grain-storage/Its-all-in-the-seal

31 M Nayak (2012) Sulfuryl fluoride—A solution to phosphine resistance? GRDC Grains Research Update, Northern Region, Issue 66, http://storedgrain.com.au/wp-content/uploads/2014/05/Northern-Update-Issue-66.pdf

32 P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014. GRDC Update Papers, 18 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

13.6 Monitoring barley

Growers are advised to monitor all grain in storage at least monthly. During warm periods in summer, if grain moisture content is near the upper end of the safe storage moisture content, monitoring every two weeks is advisable. Insect pests present in the on-farm storage must be identified so growers can exploit the best chemical and/or non-chemical control measures to control them.

Barley for domestic or export use must not contain live storage pests, and feed grades can lose nutritional value and palatability through infestations. Keeping storage pests out of planting seed grain is also important because they can reduce the germination and vigour quality of seed, with serious consequences for the next barley crop.

When monitoring stored grain through sieving, trapping and quality inspections, growers should keep records of findings. If possible, grain temperature should also be checked regularly. Any grain treatments applied should be recorded (Photo 6). [33]

Photo 6: *Keep records of findings from stored grain insect monitoring.*

Source: DAF Qld

Key points to follow when monitoring for grain insect pests:

- Sample and sieve grain from the top and bottom of grain storages every four weeks for early pest detection. Pitfall traps installed in the top of the grain store will also help with early detection of storage pests
- Holding an insect sieve in the sunlight will encourage insect movement, making pests easier to see. Sieve samples onto a white tray to make small insects easier to see. Sieves should have 2-mm mesh and need to hold at least 1 L of grain
- To identify live grain pests, place them in a clean glass container. Briefly warm the jar in the sun to encourage insect activity. Weevils and sawtoothed grain beetles can walk up the walls of the glass easily, but flour beetles and lesser grain borer cannot. Look closely at the insects walking up the glass—weevils have a curved snout at the front and sawtoothed grain beetles do not [34]

33 GRDC (2010) Aeration cooling for pest control. GRDC Grain Storage Fact sheet, September 2010, http://storedgrain.com.au/wp-content/uploads/2014/09/GSFS-5_AeratCooling-July14.pdf

34 GRDC (2013) Stored grain pests—identification. Northern and Southern regions. GRDC Grain Storage Fact sheet, June 2013, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/06/grain-storage-fact-sheet-stored-grain-pests-identification

13.6.1 GRDC Stored grain App

An App is available to record storage details such as grain type, variety, grade, quantity, paddock/source, date filled, date emptied and purchaser for farm records and quality assurance tracking. Each time a storage is monitored the app allows recording of the date, temperature, moisture content, pests identified, treatment details and any other notes.

A key feature of this application is the ability to record grain storage details and monitoring Records at the storage site regardless of mobile reception or data speed.

Simply enter the desired records and when the grower is next in mobile reception range, records can be synchronised between multiple mobile devices and/or exported to Excel.

To download go to GRDC storedgrain

See Stored Grain App–Help on the Stored Grain Information Hub website.

MORE INFORMATION

GRDC (2009) Stored grain pests, Western Region. Fact sheet.

GRDC (2014) Vigilant monitoring protects grain assets. Fact sheet.

Environmental issues

14.1 Frost

Frost damage to cereals is a significant annual production constraint for the Australian grains industry and can result in considerable yield losses. It has been estimated to cost Australian growers around $360 million in direct and indirect yield losses every year. The GRDC has long acknowledged the severe impacts of frost on crop production, and since 1999 has invested around $13.5 million in more than 60 frost-related projects.

By 2014, GRDC increased investment in frost research to establish the National Frost Initiative (NFI). This five-year, national initiative is tackling frost from several angles and aims to deliver growers a combination of genetic and management solutions to be combined with tools and information to better predict frost events.

The three-pronged initiative addresses:

- genetics – aiming to rank current wheat and barley varieties for frost susceptibility and identify more frost-tolerant wheat and barley germplasm;
- management – investigating if there are management practices or preventive products that growers could implement to reduce the impact of frost; and
- environmental prediction – focusing on predicting the impact of frost events on crop yields and mapping frost events at the farm scale to enable better risk management.

Key points include:

- In some Australian production areas, the risk of frost has increased because of widening of the frost-event window and changes in grower practices
- The risk of frost varies between and within years as well as across landscapes, so growers need to assess their situation regularly
- The occurrence of frost and subsequent frost damage to grain crops is determined by a combination of factors including: temperature; humidity; wind; topography; soil type; texture and colour; crop species and variety; and crop management
- Frost damage is not always obvious and crops should be inspected five to seven days after a suspected frost event
- Although frost damage can occur at all stages of crop development, greatest losses in grain yield and quality are observed when frosts occur between the booting and grain-ripening stages of growth

A comprehensive frost-management strategy needs to be part of annual farm planning and it should include pre-season, in-crop, and post-frost-event management tactics.

Methods to deal with the financial and personal impact of frost also need to be considered in a farm-management plan. [1]

MORE INFORMATION

https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative

14.1.1 What causes frost?

In the Australian grainbelt, frosts occur when nights are clear and calm and follow cold days. In elevated regions, frosts are often experienced after mild or even warm conditions. These conditions occur most often during winter and spring with the passage of high-pressure systems following a cold front. The clear, calm conditions encourage loss of heat from the earth and the crop itself during the night, decreasing the temperature at ground level and within the crop canopy to below 0°C. Overnight

1 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

temperatures at ground level (where heat is being lost) can be up to 5°C lower than those measured in a Stevenson screen. Differences of 10°C have been recorded.

Often frost will be more damaging when there is little soil moisture, because soil moisture adds to the heat-storage capacity of the soil.

Wind and cloud reduce the likelihood of frost by decreasing the loss of heat to the atmosphere. The extent of frost damage is determined by how quickly the temperature takes to reach 0°C, the length of time it stays below 0°C and the how far below 0°C it falls. [2]

14.1.2 Measuring temperature

Plant surfaces cool more quickly than the air surrounding them, so measuring air temperature is not entirely accurate in determining plant temperature. Temperature increases above the canopy of a crop and, if the canopy is reasonably developed, it increases below the canopy.

Temperatures recorded at a local Bureau of Meteorology (BOM) site at Stevenson screen height (standard) may not correlate well with those experienced at crop height in a particular location, and the correlation may change depending on the time of the year.

Generally, the canopy temperature is ~1.5–2.5°C lower than Stevenson screen temperature at 1.2 m at the same point in the landscape.

The most precise method of determining paddock and crop height temperature is to use accurate loggers placed at the canopy height in crop. [3]

14.1.3 The changing nature of frost in Australia

Results from modelling carried out through the GRDC-funded Managing Climate Variability project show the frequency and severity of spring radiation frosts is increasing in many parts of the Australian cropping region, including susceptible areas of WA. [4]

The length of the frost season increased across much of the Australian grainbelt by 10–55 days between 1960 and 2011, and in some parts of eastern Australia the number of frost events has increased.

CSIRO analysis of climate data over this period suggests the increasing frost incidence is due to the southerly displacement and intensification of high-pressure systems (subtropical ridges) and due to heightened dry atmospheric conditions associated with more frequent El Niño conditions during this period.

The southern-shifting high-pressure systems bring air masses from further south than in the past. This air is very cold and contributes to frost conditions.

In the WA grainbelt, there are fewer earlier frosts and a shift to frosts later into the season. [5]

2 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

3 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

4 N Lee (2016) RD&E effort continues to address significant frost issue. GRDC Media, https://grdc.com.au/Media-Centre/Media-News/West/2016/10/RD-E-effort-continues-to-address-significant-frost-issue

5 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

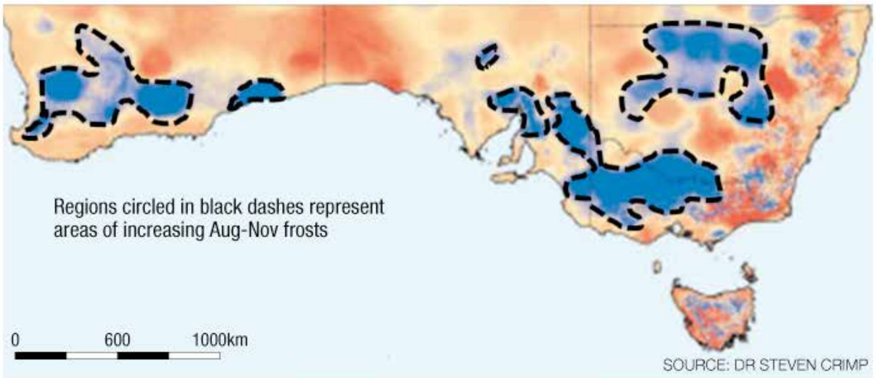

Figure 1: *Regions of increasing August–November frosts.*

Source: Steven Crimp, CSIRO

14.1.4 How does frost affect crops?

The ways in which frost can affect crops are complex.

Although ice melts at 0°C, the freezing temperature of water is not 0°C, pure water may not readily freeze until –40°C. Water and plant tissue supercool at temperatures below 0°C, to –10°C in cereals, and will only freeze or form ice crystals around small ice nucleators—the process of ice nucleation.

These ice nucleators can be particles such as dust and bacteria. Ice formation is therefore often at several degrees below 0°C and will vary depending on the concentration of plant tissue solutes and the presence of ice nucleators on plant tissues. Generally, the colder and longer the duration of subzero temperatures, the higher the probability that ice nucleation and freezing will occur.

The timing and severity of a frost may affect a crop in three ways: cold damage or chilling, desiccation and finally freezing damage (Figure 2). It is a step-wise response; that is, desiccation will not occur without prior cold damage and freezing damage will only occur after cold and desiccation damage. The freezing damage will be random throughout a crop canopy and tissues, owing to the random nature of ice nucleation and formation.

Cold or chilling damage

Cold or chilling damage occurs when plants are exposed to temperatures <10°C down to –2°C (Figure 2). If the changes in temperature are sudden, the plant is not able to increase the fluidity of membranes (largely made of fats) at the lower temperature and this compromises cellular and plant energy balance. If this occurs at critical stages in reproductive development, it can cause a few or all of the florets to abort during pollen development. The damage is not related to the formation of ice within plant tissue, although it may appear to be.

Dessication

Desiccation from ice formation occurs at temperatures from 0°C to –2°C. When plants are exposed to freezing temperature during a white frost, the dew initially freezes on the outside of the plant, but then the ice nucleation can move within the leaf through cracks in the leaf cuticle and stomata. The water inside the leaf then starts to freeze. Initially, the water around the cells freezes but it then draws water out from inside the cells and dehydrates the cells. The cells may not necessarily freeze or have ice form inside them. This process will not necessarily kill the cells, provided the dehydration and desiccation do not proceed too far. When the ice thaws, these cells can rehydrate and recover.

MORE INFORMATION

2017 DAFWA barley sowing guide https://www.agric.wa.gov.au/barley/2017-barley-variety-sowing-guide-western-australia

See the newly updated interactive FV Tool on the NVT site www.nvtonline.com.au/frost

Freezing damage

Freezing damage is the final stage of frost damage and occurs when there is rapid ice nucleation and formation of ice crystals, which punch through cell walls and membranes, physically rupturing cell walls and membranes within the cells. Freezing damage is generally not reversible, but can be limited to specific tissues within the plants by stem nodes, individual florets, individual tillers and so on.

Cereal crops are most susceptible to frost damage during and after flowering, and are susceptible at the earlier stages of booting (growth stages GS45–71; Figure 3). Losses in grain yield and quality from frost primarily occur between stem elongation and late grainfilling.

Frost damage may be sporadic across a crop within a paddock. Not all plants will show obvious symptoms and symptoms may not be obvious until five to seven days after the frost event has occurred. [6]

Barley is more frost tolerant than wheat at flowering as it flowers in the boot, however grain frost can be significant as the hulls of barley grain adhere to the grain.

Effect of wet or dry canopy

A canopy that is wet from a light shower of rain is more prone to frost damage than a dry canopy. Because ice formation requires an ice nucleator such as bacteria or dust, and rainwater contains these, when rainwater falls on a crop canopy the concentration of these nucleators is often higher. This means a slightly wet canopy from light showers will have a warmer freezing point than a dry canopy and will not supercool to as low a temperature before freezing damage occurs. [7]

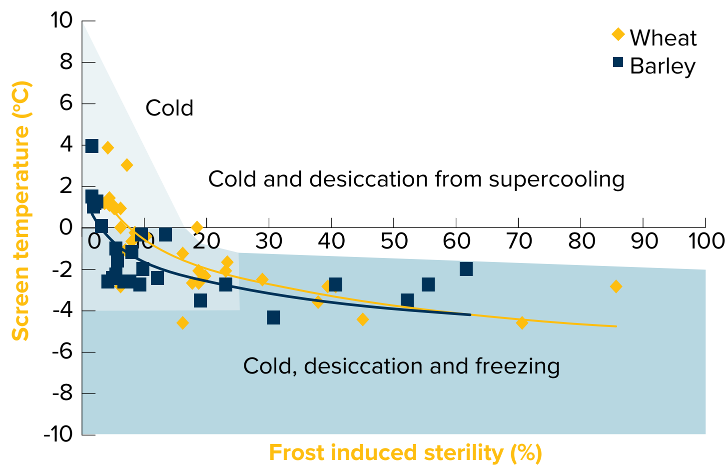

Figure 2: *Average frost-induced sterility in flowering heads of wheat and barley versus minimum Stevenson screen temperature from frosts at trials from WA, SA and NSW frost nurseries 2010–14.*

Source: GRDC

6 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

7 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

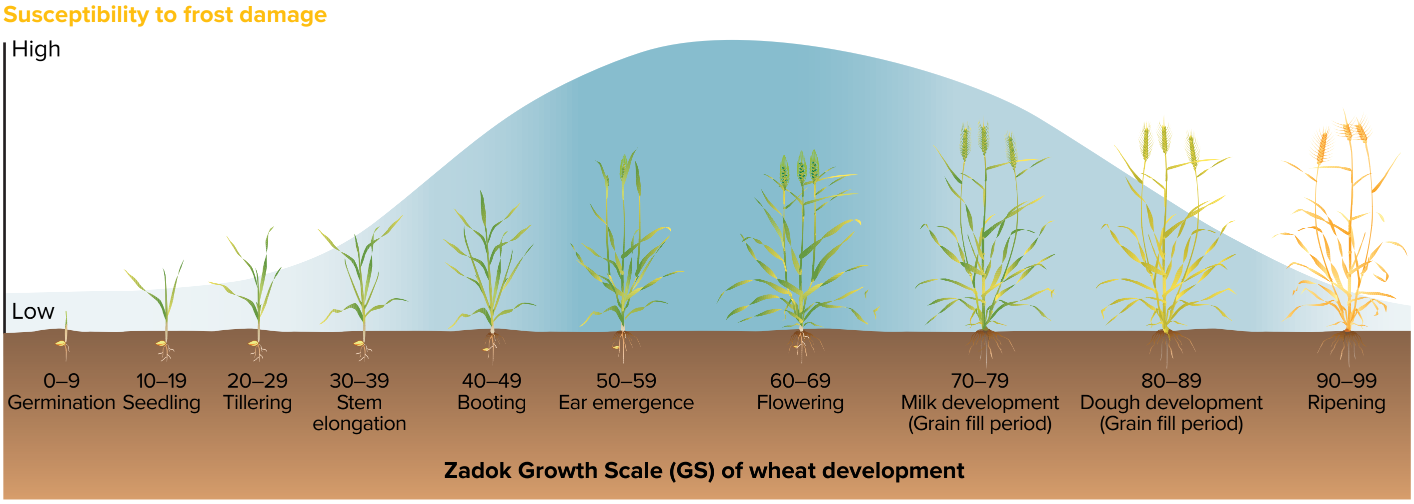

Figure 3: *Susceptibility of wheat to frost during the development cycle, with Zadoks growth stages depicted.*

Source: GRDC

14.1.5 Frost identification—what to look for and how to look for it

Key points for crop frost-damage assessment:

- Inspect crops regularly between booting and grainfilling, and when canopy temperatures fall below 1°C
- Examine the crop in the more susceptible, low parts of the landscape or at the base of a slope first and, if damaged, continue the examination in other parts of the paddock
- Walk through the crop and examine a whole plant every 20 or 30 paces; alternatively, drive a vehicle up the boom-spray tracks, stopping regularly to walk into the crop to inspect plants
- Peel back the leaves and look for stem damage
- If the head has not emerged from the boot, check to see if the head is damaged. Dissect the plant carefully with a sharp knife, from the top down, to find the head of the plant
- If the crop is flowering check the flower parts in spikelets flowering at the time
- If the crop has flowered, open the florets to check whether the grain is developing (see Photo 1b for photo of a healthy head)
- Tag a few heads with plastic insulation tape and note the stage of grainfill. Return a few days later to determine whether grain development and grainfilling are continuing. Normal grain should be extending at ~1 mm every two days until the full length is achieved [8]

Assessing the damage

After a known frost event, or when the crop canopy temperature has been near or below 0°C, the crop needs to be monitored over the following week so that management decisions can be made. The pollen and anthers are most susceptible to cold, desiccation and freezing damage both before and after head emergence.

During this time, visual symptoms of frost bleaching may not be apparent; therefore, it is essential to check individual florets for signs of damage. Inspection after two days may show anther damage, and after four days should reveal whether grain

8 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

development has been affected. Note that crops will often be affected unevenly and not all plants will show obvious symptoms.

Carefully remove the leaf sheath from around the stem and check above the nodes below the head for symptoms on the peduncle or stem of the plant. To inspect heads, peel back the glumes to inspect the reproductive structures or developing grain inside. Inspect spikelets halfway up representative heads because this is the most developed part, then above and below the centre. A hand lens may be of benefit and digital microscopes are very useful. Check multiple areas of the paddock.

A determination of yield loss can be crudely made by roughly calculating the percentage of affected florets and multiplying by the expected yield. For example, a barley crop with an estimated yield of 2.5 t/ha is frosted and a sample of 20 heads is taken from the crop; of the 20 heads, 12 are completely filled and eight half-filled with grain. This would represent a yield loss of: 8/20 × 50% × 2500= 500 kg/ha. [9]

Juvenile frost damage

Frost damage frequently occurs to crops in the juvenile stage in parts of Australia; however, there is usually little or no yield loss because there is ample time for the plant to compensate with new leaves or tillers.

The worst damage occurs when the growing point of the plant is above ground level and there is dense mulch on the soil surface, usually associated with the retention of large amounts of stubble. The growing point is embedded in the stubble or at the junction of the stubble and soil surface. Although stubble insulates anything it covers, the low density and light colour of stubble can produce very low temperatures on and within the stubble itself.

Leaves can often be damaged by frost, showing white, often twisted, bleaching of emerging leaves and yellowing of emerged leaves. Usually leaf damage is inconsequential but, occasionally, severe photosynthetic impairment can occur to flag leaves, resulting in smaller grain and lower yield. [10]

Stem-elongation frost damage

At the very early stage of development, the head is protected to a degree by the leaf sheaths surrounding it. However, during stem elongation (GS30–39), the developing head and stems can still be frozen by very severe frosts (Photo 1 and Photo 2.)

Carefully dissect through the leaf sheaths with a sharp knife to find the approximate position of the head and then unwind the remaining tissue to expose the small head. At this stage of development, the frosted heads or tillers will not emerge (Photo 1a) and the crop will re-tiller.

Frost damage to the stem may be evident as blistering and bleaching of the stem internodes (Photo 1a). Sometimes this is associated with damage to the head, but not always, as in Photo 3, where the stem is damaged but not the developing head.

Experience in the 2014 season indicates crops can re-tiller and achieve reasonable yield levels, provided temperatures are favourable and either soil moisture is good or spring rainfall is adequate. [11]

9 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

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Photo 1: *(a) Damage to developing wheat heads from frost at stem elongation: one healthy head (left) and five frosted heads (FS, frosted stem). (b) Close up of a healthy wheat head. Frost occurred at ~GS32, and photos were taken at ~GS37, two to three weeks later.*

Photos: (a) Karl Moore and (b) Ben Biddulph, DAFWA

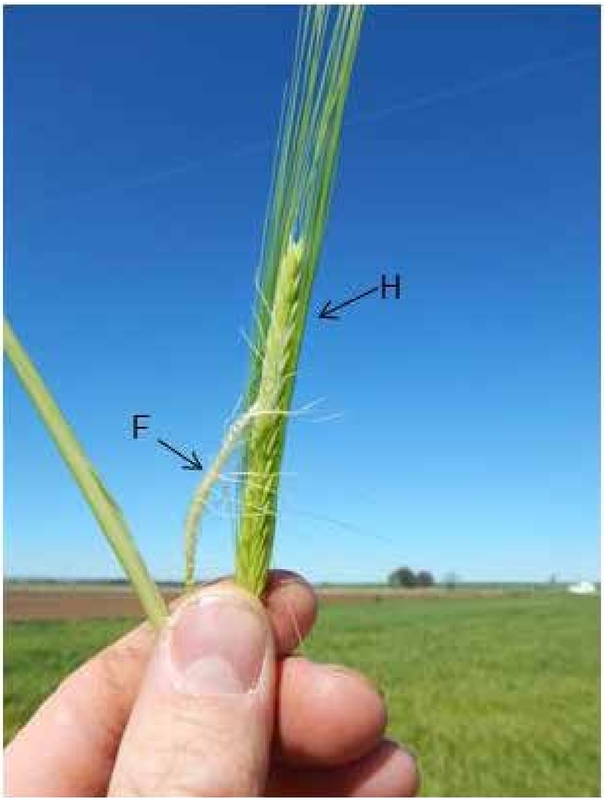

Photo 2: *Damage to the developing barley head from frost at stem elongation ~GS35; frosted head (F) and healthy head (H). Photos were taken at two to three weeks after the frost at ~GS49.*

Source: Ben Biddulph, DAFWA

Photo 3: *Damage to the stem internodes, but viable head.*

Source: Ben Biddulph, DAFWA

Cold damage to developing head prior to head emergence

Prior to head emergence at GS51, the head is protected to a degree by the leaf sheaths surrounding it.

If chilling or frost occurs during the sensitive stages of pollen meiosis (GS39–45) and early pollen development (GS45–65), the head or particular florets can stop development and abort.

The damage at this stage is quite distinctive and heads emerge with a pale, undeveloped colour from white (GS39; Photo 4, left panel) to light green (GS51; Photo 4, right panel), depending on the stage of pollen development at which the florets were aborted (the later in development the greener). In most cases, this is not from freezing damage but from the damaging effects of cold and desiccation associated with the frost event causing a generalised stress response and pollen abortion.

Photo 4: *Cold- and desiccation-induced sterility and floret abortion from frost at booting during: left, pollen meiosis (flag leaf emergence ~GS39); centre, pollen development (booting ~GS45); right, pollen maturation (~GS49, ear peep). Photos taken at flowering after head emergence, two to three weeks after the frost events.*

Photos: Sarah Jackson

Cold and desiccation damage during flowering

Cold and desiccation damage to barley heads after partial or complete head emergence (GS51 onwards) can occur when canopy temperature drops to ≤0°C.

Damage may not be visible for several days unless the heads are closely inspected and the reproductive parts inside the florets are inspected for damage as in Photo 5 and 13. A digital microscope is useful for aiding identification. [12]

During normal head development, immature anthers are light green, turning yellow on maturity just prior to flowering (Photo 6a) and prior to extruding from the floret. Healthy anthers turn from yellow prior to pollen release (Photo 6a) to white after they have released the yellow pollen (Photo 6b, c).

After a frost event, the anther may remain light green to yellow for one to two days before turning white and shrivelled (as in Photo 6d). Often anthers have a water-soaked appearance (similar to frozen lettuce leaves). The tell-tale sign of frost damage is white anthers and ovules that are not swollen or developing (Photo 6b, d).

The stigma, style and ovary (or the female reproductive parts) may also be affected. The stigma in a healthy plant will be feathery, sticky and greenish-white before pollination (Photo 6a). A fertilised stigma has a light coating of yellow pollen cells and curls up (Photo 6b, c), whereas a frost-affected, unfertilised stigma will become off-white to brown and shrivelled in appearance (Photo 6d).

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Photo 5: *A head frosted at flowering (GS65) (left) compared with an unfrosted head at two to three days after the frost event, when at GS70.2.*

Source: Pia Scanlon, DAFWA

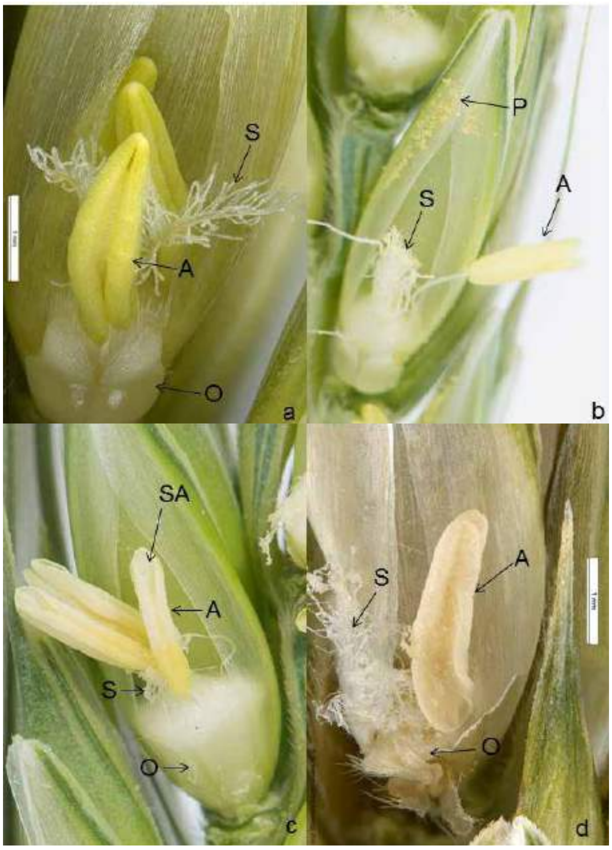

Photo 6: *(a) Healthy floret about to flower: anthers (A), stigmas (S) and ovaries (O) of wheat within a floret. (b) Freshly fertilised floret: pollen (P). (c) Fertilised and swollen ovule: split anthers (SA). (d) Frosted floret. Photo of frosted floret taken at GS70.2 of heads frosted just prior to flowering (GS61).*

Photos: Pia Scanlon, DAFWA

This damage at flowering is mainly from the cold and the desiccating effects of the ice formation during a frost event. With more severe frost events, when freezing damage occurs, the symptoms on the internal reproductive structures are similar, but there can be more obvious blighting of the heads (Photo 7).

Freezing damage to head and reproductive structures

If the head is partially emerged from the flag leaf during a frost, part or all of the head may be frozen and exhibit a blighted or bleached appearance several days after the frost (Photo 7).

Blighting usually affects only a small proportion of the heads as in Photo 7, but is also often associated with frost damage to the reproductive structures inside, which requires closer inspection (as in Photo 6).

After about one week, cold, desiccation and freezing head damage becomes more obvious and may not require dissection. Because of the low fertilisation of the grain, whole heads begin to lose their green appearance, turning yellow as a result of resource reallocation to the development of new tillers; in severe cases the heads that have been frozen turn white.

The florets do not fill with grain, so the heads will feel soft, papery and spongy when squeezed, due to physical damage from the ice formation. Heads are lighter in weight than normal, with the lack of grain development and grainfilling. [13] Barley is

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more frost tolerant than wheat at flowering as it flowers in the boot- but grain frost can be significant as the hulls of barley grain adhere to the grain.

Photo 7: *Desiccation and freezing damage, often called frost blighting, of three wheat heads compared with a healthy head (right). Frost event was at ~GS55 and the photo was taken seven days later at GS61. Barley is also affected by frost, but to a lesser extent than wheat.*

Source: Pia Scanlon, DAFWA

Freezing damage during grain development and grainfilling

After flowering, the head is less susceptible to cold and desiccation damage but still susceptible to freezing damage. However, flowering is not synchronous, so although the centre of a head may have completed flowering the spikelets towards the top and bottom may still be flowering.

When frosted during water and milk development (GD in Photo 8; GS70.2–79), the developing grains may be frozen and do not continue to develop. They turn a white to grey colour and become shrivelled and dry instead of plump and full of clear, sugar-filled solution. These grains are not normally retained in a header sample and they often shatter easily at maturity.

When frosted during dough development and grainfilling (GF in Photo 8; GS80–89), the grains often do not abort but become scalloped and continue to develop. Often they initially develop a dark-green, water-soaked appearance that is visible through the outside of the grain. Squeezing these grains at the early-dough stage (GS81), the contents will be grey and liquid instead of white, slippery and viscous.

Frosts often follow the cycle of weather patterns; therefore, crops are often frosted at several successive stages of development and will exhibit a combination of different symptoms, as seen in Photo 8, where the same head has damage from frost at flowering (GS61), grain development (GS70.8) and early grainfilling (GS81). These symptoms also change over time, depending on the time since the frost damage occurred (Photo 9).

Wheat that has been frosted at the grainfilling stages is a little more resilient to the effects of frost, often showing grains with shrunken sides and slightly wrinkled, and will have a reduced grain weight. These grains may be present in a header sample and will be counted as frost-affected grains (Photo 10). [14]

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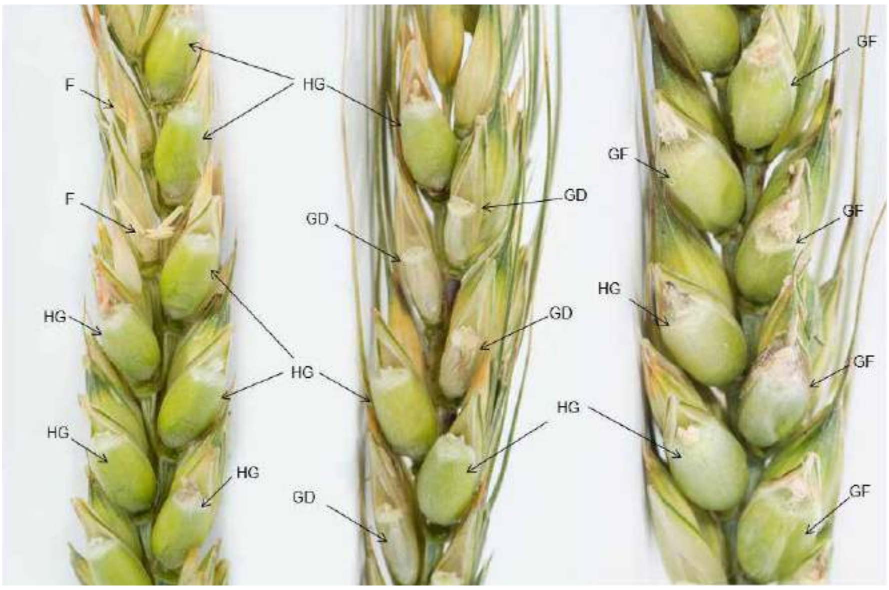

Photo 8: *Wheat head that has been frosted at flowering (GS65; F) and at grain development (GS70.8; GD), and partially frosted during grainfilling (GS81; GF). Frost-affected grains starting to shrivel (GD) to form a pinched or scalloped appearance (GF) compared with healthy grains (HG). Frosts occurred at ~GS65, GS70.8 and GS81, and the photo was taken at ~GS83.*

Source: Pia Scanlon, DAFWA

Photo 9: *Head partially frosted at flowering (GS65, left); frosted at flowering and grain development (GS65 and GS70.8, centre); and at flowering, grain development and grainfilling (GS65, GS70.8 and GS81, right). Photo was taken of heads of the same variety from a time-of-sowing trial indicating cumulative damage and the change in symptoms with time after frost events.*

Source: Pia Scanlon, DAFWA

Photo 10: *Grains collected at maturity that are (a, b) unfrosted, or frosted (c) at GS70.5–71; (d) GS73–75; (e) GS75–79; (f) GS81–83; (g) GS83–87.*

Source: GRDC

Freezing damage to the peduncle

At and after ear peep (GS51) the peduncle is susceptible to freezing damage. Two types of peduncle damage are frequently found after flowering. Type 1 damage occurs above the first node, and Type 2 is damage at, or above, the attachment of the flag leaf.

Type 2 damage is normally most severe after a slight rainfall event at ~GS51–55 when the rain causes a small amount of water to collect inside the leaf sheath surrounding the most undeveloped section of the peduncle (Photo 11).

Initially, one to three days after the frost event, the head and peduncle are easily pulled from the standing crop and the damaged stem has a dark-green water-saturated appearance (Photo 11, upper panel). This is common for Type 1 and Type 2 damage. Sometimes a slightly less severe symptom of Type 1 will be blistering.

At three to seven days after the frost event, the head and peduncle cannot be pulled from the standing crop with Type 2 damage, and in sandy soils the whole plant will pull out. This depends on the severity of the frost. Often the stems can be pulled out because there is complete tissue death above the node. It is due to lignification and scarring of the frosted section of the peduncle (Photo 11, lower panel close-up). This section is often light green and the surface of the peduncle is rough in this area. The head and peduncle can be easily pulled out with Type 1 damage and distinct narrowing of the peduncle just above the node will be obvious.

Around five to ten days after the frost event, the stem (or peduncle) when frosted will have a light-green or white ring around it with Type 2 damage (Photo 11, lower panel, and Photo 12) and will feel rough and hard.

If the stem frost is not very severe and the reproductive tissues have not been destroyed by the same frost event, sugar and water will continue to be taken up by the developing head. The plants may recover and achieve a 20–40% reduced yield.

Recovery and compensation is greatest with ample soil water and mild temperatures. Severe Type 1 peduncle frosts can result in 100% yield loss. Viability of the tissue can be tested by taking a sample of heads together with their stalks, cutting cleanly with a knife low on the plant and placing the samples in a blue food-dye solution overnight. If the tissue is viable, the heads will turn blue and grainfill may proceed normally.

More severely affected stems can become distorted, and sugar and water flow may be restricted to the head, reducing grainfill and resulting in high screenings.

Frost damage can also weaken the stem, causing lodging after strong winds, making harvest difficult. Blistering and/or cracking of the nodes and leaf sheath may also occur in severe events. [15]

Photo 11: *Left: stem frost damage at the bottom or growing point of the peduncle taken the morning after a frost event. Right: photo taken three weeks after the frost, when at GS61. The crop canopy was at ~GS55 with stem-frost-affected peduncles occurring in tillers between ear peep (GS51) and partial head emergence (GS55).*

Photos: left, Ben Biddulph; right, Pia Scanlon, DAFWA

Photo 12: *Peduncle stem damage showing light-green region (S) and bleached heads with infertile florets (B).*

Source: DAFWA

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14.1.6 Risk management for frost

The variability in the incidence and severity of frost means growers need to adopt a number of strategies as part of their farm-management plan. These include pre-season management tactics, in-season tactics and strategies following the incidence of frost.

Pre-season management tactics

Two types of pre-season management tactics are available for growers: the first at the level of farm-management planning and the second within identified frost zones of a farm.

Farm-management planning:

Step 1: Assess personal approach to risk. Grower should consider their personal approach to risk in your business—every individual will have a different approach. Growers should identify and measure the extent of the risk, evaluate risk-management alternatives and tailor the risk advice according to their risk attitude. The risk of frost can often drive conservative farming practices, which should be carefully reviewed regularly in light of up-to-date research.

Step 2. Assess frost risk of property. Carefully consider the risk of the property incurring frosts, based on the location, historic seasonal records and forecasts. Spatial variability across the landscape should also be considered: cold air will flow into lower regions. Temperature-monitoring equipment, such as Tinytag® data loggers and iButtons, and weather stations, are commercially available for on-farm determination of temperature variability across a landscape.

Step 3. Diversify the business. A range of enterprise options should be considered as part of a farm-management plan to spread financial risk in the event of frost damage. This will depend on the location of the business and the skillset of the grower; however, the largest financial losses with frost have occurred where growers have a limited range of enterprises or crop types.

Step 4. Zone the property and/or paddock. Paddocks or areas in paddocks that are prone to frost can be identified through experience. Precision tools such as topographic, electromagnetic and yield maps, and temperature monitors can be used to locate susceptible zones. This can help to determine the appropriate management practice to mitigate the incidence of frost.

Be aware that frost-prone paddocks can be high-yielding areas on a farm when frosts do not occur. Once the farm has been zoned for potential frost incidence, the following tactics can be considered. [16]

Frost zone management:

Step 1. Consider enterprise within a zone. The use of an identified frost zone should be carefully considered; for example, consider grazing, hay or oat production and avoiding large-scale exposure to frost of highly susceptible crops (e.g. field peas) or expensive crops (e.g. canola). It may be prudent to sow annual or perennial pastures on regularly frosted areas to avoid the high costs of crop production.

Step 2. Review nutrient management. Targeting fertiliser—nitrogen (N), phosphorus (P), potassium (K)—and seed rates on high-risk paddocks to achieve realistic yield targets should minimise financial exposure, reduce frost damage and increase whole paddock profitability over time. These nutrients could be reallocated to lower risk areas of the farm. Although high rates of N increase yield potential, they also promote vegetative biomass production and increase the susceptibility of the crop to frost. Using conservative rates of N at seeding and avoiding late top-ups appear to result in less crop damage. Crop deficiency of K or copper (Cu) may increase susceptibility to frost events. This can be assessed from initial soil tests and with plant-tissue testing. Copper deficiency can be ameliorated with a foliar spray pre-flowering and as late as

16 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

the booting stage to optimise yield, even in the absence of frost. Potassium plays a role in maintaining cell water content in plants, which can influence tolerance to frost. Plants deficient in K are more susceptible to frost. Soils deficient in K could benefit from increasing K levels at the start of the growing season. There is no evidence that applying other micronutrients has any impact in reducing frost damage.

Step 3. Modify the soil heat bank. The soil heat bank is important for reducing the risk of frost (Figure 4). Farming practices that manipulate the storage and release of heat from the soil heat bank into the crop canopy at night can reduce the impact of a frost event. [17] Agronomic practices that may assist with storing heat in the soil heat bank include:

- Practices that alleviate non-wetting sands, such as clay delving, mould-board ploughing or spading, which have multiple effects, including increasing heat storage, nutrient availability and infiltration rate.
- Rolling the soil surface. Rolling sandy soil and loamy clay soil after seeding can reduce frost damage and prepares the surface for hay cutting, should it be necessary.
- Reducing the amount of stubble. Stubble loads >1.5 t/ha in low-production environments (2–3 t/ha) and 3 t/ha in high-production environments (3–5 t/ha) generally increase the severity and duration of frost events and can have a detrimental effect on yield under frost.
- Lowering seeding rates. Seeding rates at half of normal agronomic practice can reduce frost severity and damage by creating a thinner canopy and more tillers, resulting in a spread of flowering time. However, weed competitiveness can be an issue.
- Cross-sowing. Crops sown twice with half the seed sown in each direction have a more even plant density, and this can release heat from the soil heat bank more slowly to warm the crop canopy at head height in early morning, when frosts are more severe. However, this practice, increases sowing costs.

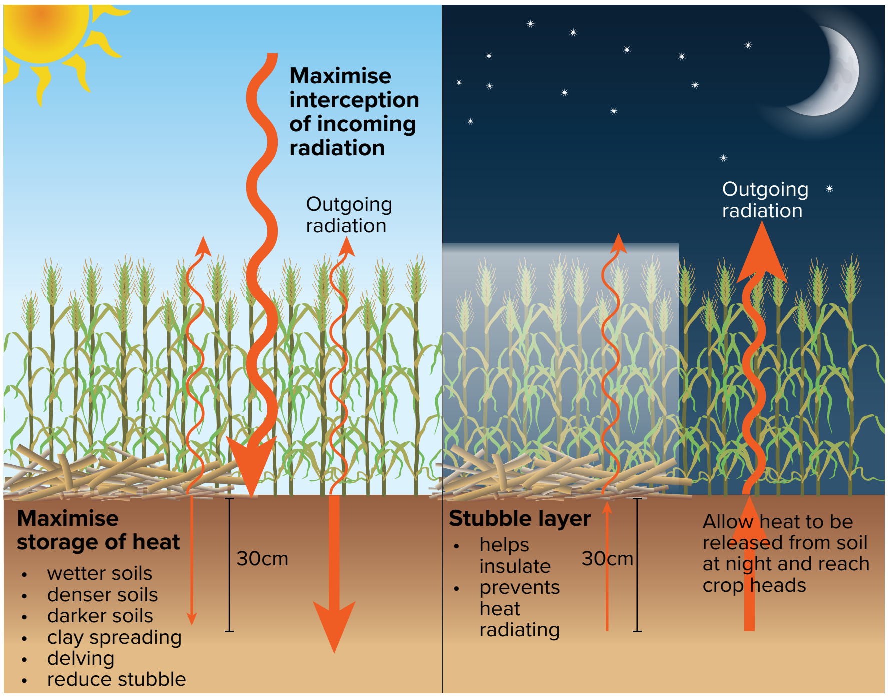


Figure 4: *Soil heat bank, illustrating the role it plays in capturing heat during the day and radiating heat into the crop canopy overnight to warm flowering heads and minimise frost damage.*

Source: GRDC

17 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

Step 4. Select appropriate crops. Crop selection is an important factor to consider for frost-prone paddocks. For example, hay harvests biomass; therefore reproductive frost damage does not reduce yield and in some cases can improve quality. Pasture rotations are a lower risk enterprise and oats are the most frost-tolerant crop during the reproductive stage. Barley is more tolerant than wheat at flowering; however, barley may have less frost tolerance during grainfill. Canola is an expensive crop to risk on frost-prone paddocks because of high input costs. Yield Prophet® is a useful tool to match the flowering time of varieties to your farm's prevailing conditions.

Step 5. Manipulate flowering time of the cropping program and specific crops. When sowing in frost-risk areas, ensure that the flowering window of the cropping program is spread widely. Consider the following:

- Use more than one variety, and varieties with different phenology drivers, and manipulate sowing date so crops flower over a wide window throughout the season. Flowering later than the frost window will invariably result in lower yields due to heat and moisture stress.
- Stage sowing dates over three to six weeks. If sowing just one variety, this would provide a wide flowering window. If the whole program is set to flower over a two-week period, it is exposed to a greater risk of frost damage but the yield potential is maximised in the absence of frost. Even with this strategy in place it is possible to have a number of frost events that cause damage. Flowering over a wide window will probably mean some crop will be frosted but the aim is to reduce extensive loss.
- To minimise frost risk, a mix is needed of sowing dates, crop types and maturity types to incorporate different frost-avoidance strategies in the cropping system. In years of severe frost, regardless of the strategy adopted, it may be difficult to prevent damage.
- Trials have shown blending a short-season variety with a long-season variety is an effective strategy. However, the same risk-spreading effect can be achieved by sowing one paddock with one variety and another paddock with the other.
- Sowing at the start of a variety's preferred window will achieve higher yields than sowing late, for the same cost. Sowing time therefore remains a major driver of yield in all crops, with the primary objective of achieving flowering after the risk of frost has passed but before the onset of heat stress. Any advantage of sowing late to avoid frost risk is often outweighed by the gains from sowing on time to reduce heat and moisture stress in spring.

Step 6. Fine-tune cultivar selection. No wheat or barley varieties are tolerant to frost. Therefore, consider using varieties that have lower susceptibility to frost during flowering. This will manage frost risk of the cropping program while maximising yield potential. However, do not select less susceptible varieties for the whole cropping program if there is an opportunity-cost of lower yield without frost. The National Variety Trials website is a useful source for ranking information which can be used to fine-tune frost-risk management of new varieties after they have been selected. A new variety should be managed based on current management of known varieties of similar ranking.

- Example 1: Figure 5 shows the ranking of adapted varieties for the western region; a grower in the Upper Great Southern may be considering how to incorporate La Trobe⁽ᴾ⁾ and Scope CL⁽ᴾ⁾ in their cropping program to complement Hindmarsh⁽ᴾ⁾. From a frost-risk-management perspective, La Trobe⁽ᴾ⁾ has sterility under frosts and sowing- or flowering-time response similar to Hindmarsh⁽ᴾ⁾; hence, it can essentially be treated the same in terms of sowing or flowering time and position in the landscape. Scope CL⁽ᴾ⁾ also has similar sterility under frost but is slightly later maturing than Hindmarsh⁽ᴾ⁾, so may be planted five to seven days earlier with a frost risk similar to Hindmarsh⁽ᴾ⁾.
- Example 2: Figure 5 shows the ranking of adapted varieties for the low–medium-rainfall cropping areas of the southern region. A grower may be considering how to incorporate La Trobe⁽ᴾ⁾ and Scope CL⁽ᴾ⁾ in their cropping program to complement Hindmarsh⁽ᴾ⁾. From a frost-risk-management perspective, La Trobe⁽ᴾ⁾ has a slightly higher sterility under frosts than, and the same sowing- or

flowering-time response as Hindmarsh⍉; hence, it may need to be sown in less frost-prone parts of the landscape. Scope CL⍉ has slightly lower sterility under frost, but is also slightly later maturing than Hindmarsh⍉, so may be planted five to seven days earlier with a slightly lower frost risk than Hindmarsh⍉.

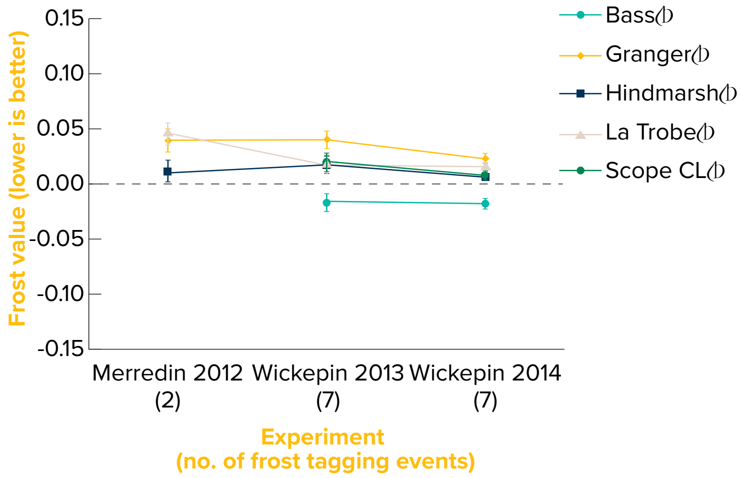


Figure 5: *Frost value (FV) of sterility under flowering frost for five barley varieties tested at Merredin and Wickepin, Western Australia. FVs are presented along with prediction standard error bars. The number of frost events is indicated in parentheses for each site and year. Lower FVs are better.*

Source: GRDC

Management tactics within season

The progress of the season should be monitored by regularly assessing weather forecasts and crop development in relation to frost incidence. Decisions may need to be made to use available in-crop management tactics to mitigate frost damage during the season.

Grazing

Trials in the south of WA and in SA have shown that grazing of cereal crops in winter to delay flowering can reduce grain yield losses from spring frosts by extending the flowering date. These crops can also provide extra fodder for livestock.

This management tactic can be used not only to manipulate a crop's flowering time after seeding but also to reduce the amount of crop biomass, which will reduce frost incidence, and to compact the soil, which increases the soil heat-bank capacity.

The key message is to graze early (at the 4- or 5-leaf stage or even earlier) and intensively for a short period. Grazing for 14 days delays flowering by about 7 days. Grazing after first node (GS31) will significantly delay flowering and reduce crop yield. High stock numbers are often required.

Extra nutrients

Conservative input strategies should be adopted for frost-prone areas, and minimal or no additional nutrients should be applied during the season. Copper is the only exception, tissue-test for copper during tillering and apply foliar copper at booting if tissue samples are identified as marginal. [18]

Manage N to frost risk; avoid late N top-ups in zones and paddocks identified during pre-season planning as being at higher frost risk.

MORE INFORMATION

https://grdc.com.au/archive/key-issues/grazing-dual-purpose-crops-in-western-australia/details

18 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

Post-frost management tactics

Once a frost event (especially at or after flowering) has occurred, obtain an estimate of the yield loss suffered. This can be done by inspecting the affected crop and randomly collecting a sample of heads to estimate the yield loss.

Then consider options for the frost-damaged crop. Tillers already formed but lower in the canopy may become important and new tillers can grow after frost damage has been incurred, depending on the location and severity of the damage. These compensatory tillers will have delayed maturity but, where soil moisture reserves are high, or it is early in the season, they may be able to contribute to grain yield.

Option 1. Take through to harvest

If the frost occurs prior to or around GS31–32, most cereals can produce new tillers to compensate for damaged plants, provided spring rainfall is adequate. A later frost is of more concern, especially for crops such as wheat and barley, because there is no time for compensatory growth. The required grain yield to recover the costs of harvesting should be determined by using gross margins.

Option 2. Cut and bale

This is an option when late frosts occur during flowering and through grainfill. Assess crops for hay quality within a few days of the frost event and be prepared to cut a larger than intended area for hay, because grain yield may be reduced. Hay cutting can also be a good management strategy to reduce stubble, weed seedbank and disease loads for the coming season. This may allow more rotational options in the following season to recover financially from the frost; for example, to go back with cereal on cereal in paddocks cut early for hay. Hay cutting can be an expensive exercise, and growers should have a clear path to market or a use for the hay on-farm before committing costs to this practice.

Option 3: Grazing, manuring and crop topping

Grazing is an option after a late frost, when there is little or no chance of plants recovering, or when hay is not an option. Spraytopping for weed seed control may also be incorporated, especially if the paddock will be sown to crop the next year. Ploughing in the green crop returns organic matter and nutrients to the soil, manages crop residues and weeds, and improves soil fertility and structure. The economics need to be considered carefully. [19]

14.1.7 Harvesting and marketing frosted grain

The effect of frost on yield and quality of grain depends on the stage of crop development; generally, as development progresses through grainfilling, the grains become drier and less frost-susceptible.

- If affected during flowering, the grain is aborted and yield is reduced, but rarely are there any negative impacts on quality of remaining grain
- If affected during the watery stage, grain does not develop any solids and frosted grains do not appear in the sample. Unfrosted grains can compensate and are often larger, with high a test weight
- Where there is frost at the milk stage of development, grains may continue to develop, but will be light and shrivelled. Grain usually has a low hectolitre weight and high screenings, but this can usually be minimised by adjusting header settings
- At late-dough stage, frost can result in wrinkly or scalloped grains. Again, the low hectolitre weight and higher screenings and further cleaning may be required

In frost-damaged crops, adjust header settings to maximise the quality of the grain harvested.

19 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

Higher classification of frost-affected grain may be achieved by cleaning grain, but the capacity and economics need to be carefully considered. [20]

14.1.8 Retaining seed from frosted crops

Grain that forms when a flowering frost has occurred is often plump and makes good-quality seed; however, where frost occurs during grainfill, the germination and establishment of these damaged grains is compromised.

Even after grading, frosted grain can have 20–50% lower crop establishment than unfrosted grain in the following season. As a result, growers need to retain more seed than usual, sow into an optimum seedbed and increase seeding rate to compensate for lower crop germination and lower vigour of frosted grain.

Growers are advised to:

- retain and grade seed only from the less frost-damaged areas
- test germination prior to sowing and adjust seeding rates accordingly to ensure uniform crop establishment
- plan not to retain frost-affected seed for more than one year. [21]

14.1.9 Recovering from frost

Dealing with the financial and personal impact of frost damage:

- Act early if frost damage has had a serious financial impact
- Prepare a future business plan and, where necessary, seek advice on tactics from consultants and rural counsellors
- Communicate and discuss the likely impact of the frost with your financial adviser and prepare a recovery plan with the bank and other finance providers
- Assess the physical, financial and social situation factually so that decisions are based on the best information
- Develop alternative strategies for dealing with frosted crops in future programs and for how finances may need to be adjusted
- Prepare a draft budget and physical plans for next year and provide this information to business partners and financiers
- Develop a written plan of your proposed action and review it as information and circumstances change
- Assess the personal impact, remaining alert to the fact the frost can be an emotional rollercoaster and trigger feelings of depression, grief and loss
- Maintain contact with family, friends and colleagues and seek professional advice if necessary. Also, be aware of the impact on your neighbours and community
- Remember to assess your own situation and avoid getting caught up in negativity
- Frost can be easily forgotten from one year to the next. Do not let early rains distract you from the plans to spread or reduce risk [22]

14.1.10 National Frost Initiative

The objective of the GRDC's National Frost Initiative is to provide the Australian grains industry with targeted research, development and extension solutions to manage the impact of frost and maximise seasonal profit.

The initiative is addressing frost management through a multidisciplinary approach incorporating projects in the following programs:

20 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

21 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

22 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

MORE INFORMATION

DAFWA (2016) Frost and cropping.

GRDC (2015) Climate forecasting. GRDC Ground Cover: Issue 114.

GRDC (2015) Agronomist's guide to information for managing weather and climate risk. GRDC Update Paper.

GRDC (2014) Farm business management: Simple and effective business planning. Fact Sheet.

GRDC (2014) Frost. GRDC Ground Cover Issue 109

GRDC (2013) Farm Business Management: Making effective business decisions. Fact Sheet.

GRDC (2011) Back Pocket Guide: Cereals—frost identification

GRDC: Cereal growth stages

Weather apps: CliMate, Meteye, DAFWA weather stations app. AgExcellence Alliance has an app listing on their website http://agex.org.au/farming-applications/.

Plant development apps: MyCrop, Flower Power

Temperature monitors: HOBO Data Loggers

- Genetics: developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.
- Management: developing best practise crop canopy, stubble, nutrition and agronomic management strategies to minimise the effects of frost, and searching for innovative products that may minimise the impact of frost.
- Environment: predicting the occurrence, severity and impact of frost events on crop yields and frost events at the farm scale to enable better risk management. [23]

14.2 Soil moisture issues for barley

Availability of soil moisture has major interactions with the rate of transpiration and therefore photosynthetic production.

Moisture stress

Moisture stress slows photosynthesis and leaf-area expansion, reducing dry-matter production. It also limits root growth, which reduces nutrient uptake. This is important in areas with low rainfall. The period of crop growth is restricted at the start of the season by lack of rainfall and at the end of the season by water deficits and high temperatures. There is therefore little scope in these areas to lengthen the period of crop growth to increase dry-matter production and yields. [24]

Waterlogging

Barley is very susceptible to waterlogging and is less tolerant than wheat or oats. Barley should not be grown on soils where waterlogging is likely to occur for periods of >2 weeks.

Waterlogging occurs when rainfall exceeds the infiltration rate, water-holding capacity and internal drainage rate of the soil profile. Waterlogging fills the air spaces of the soil with water, reducing the oxygen concentration. This limits root function and survival, resulting in decreased crop growth or plant death. Availability of N and other nutrients may also be reduced. The lack of nutrients slows the rate of leaf growth and accelerates leaf death. Tiller initiation is also slowed, reducing the growth and survival of tillers. These conditions contribute to yield reductions. The amount of reduction depends on the stage of plant development when the waterlogging occurs, the duration of the waterlogging and the soil quality. [25]

23 GRDC (2016) Tips and Tactics: Managing frost risk Northern, Southern and Western Regions. GRDC Fact sheet, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

24 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series, Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

25 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth & development. PROCROP Series, Industry & Investment NSW/NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

Marketing

The final step in generating farm income is converting the tonnes produced into dollars at the farm gate. This section provides best-in-class marketing guidelines for managing price variability to protect income and cash flow.

Figure 1 shows a grain selling flow chart that summarises:

- The decisions to be made
- The drivers behind the decisions
- The guiding principles for each decision point

The reference column refers to the section of the GrowNote™ where you will find the details to help you in making decisions.

Decisions	Decision drivers	Reference	Guiding principles
When to sell?	**Production risk** – estimate tonnage **Target price** – cost of production **Cash flow requirements**	1.2.1 1.2.2 1.2.3	Don't sell what you don't have Don't lock in a loss Don't be a forced seller
How to sell?	**Fixed price** – maximum certainty **Floor price** – protects downside **Floating price** – minimal certainty	1.3.1	If increasing production risk, take price risk off the table. Separate the pricing decision from the delivery decision.
Which markets to access?	**Storage and logistics** – on farm, private, BHC's **Costs of storage / carry costs**	1.4 1.4.1 1.4.2	Harvest is the first priority Storage is all about access to markets Carrying grain is not free
Executing the sales?	**Contract negotiations and terms** **Counterparty risk** **Relative commodity values** **Contract (load) allocations** **Read market signals (liquidity)**	1.5.1 1.5.6	Seller beware Sell valued commodities, not undervalued commodities Sell when there is buyer appetite Don't leave money on the table.

Figure 1: *Grain Selling – best practice in conversion of tonnes to dollars.*

This figure provides a summary via a GRAIN SELLING flow chart defining:

- The decisions to be made
- The drivers behind the decisions
- The guiding principles for each decision point

References are made to the section of the GrowNote you will find the detail

The grower will run through a decision-making process each season, because growing and harvesting conditions, and prices for grains, change all the time. For example, in the seven years to and including 2015, Kwinana feed barley values varied A$40–$160/t, a variability of 15–95% (Figure 2). For a property producing 500 tonnes of feed barley this means $20,000–$80,000 difference in income, depending on timing of sales.

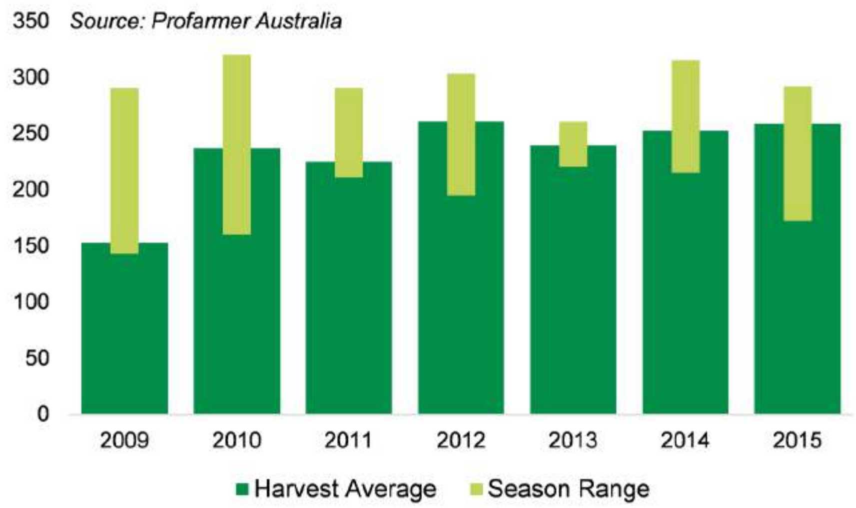


Figure 2: *Intra-season variance of Kwinana Barley values. Note to figure two: Kwinana feed barley values have varied A$40-$160/t over the past 7 years (representing variability of 15-95%). For a property producing 500 tonnes of feed barley this means $20,000-$80,000 difference in income depending on timing of sales.*

Source: Profarmer Australia

15.1 Selling principles

The aim of a selling program is to achieve a profitable average price (the target price) across the entire business. This requires managing several unknowns to establish a target price and then work towards achieving the target price.

Unknowns include the amount of grain available to sell (production variability), the final cost of producing the grain, and the future prices that may result. Australian farm-gate prices are subject to volatility caused by a range of global factors that are beyond the grower's control and are difficult to predict.

The skills growers have developed to manage production unknowns can also be used to manage pricing unknowns. This guide will help growers manage and overcome price uncertainty.

15.1.1 Be prepared

Being prepared by having a selling plan is essential for managing uncertainty. The steps involved are forming a selling strategy, and forming a plan for effectively executing sales. The selling strategy consists of when and how to sell.

When to sell

Knowing when to sell requires an understanding of the farm's internal business factors, including:

- production risk
- a target price based on the cost of production and the desired profit margin
- business cashflow requirements

How to sell

Working out how to sell grain is more dependent on external market factors, including:

- the time of year, which determines the pricing method
- market access, which determines where to sell
- relative value, which determines what to sell

The following diagram (Figure 3) lists the key principles to employ when considering sales during the growing season. Exactly when each principle comes into play is indicated in the discussion below of the steps involved in marketing and selling.

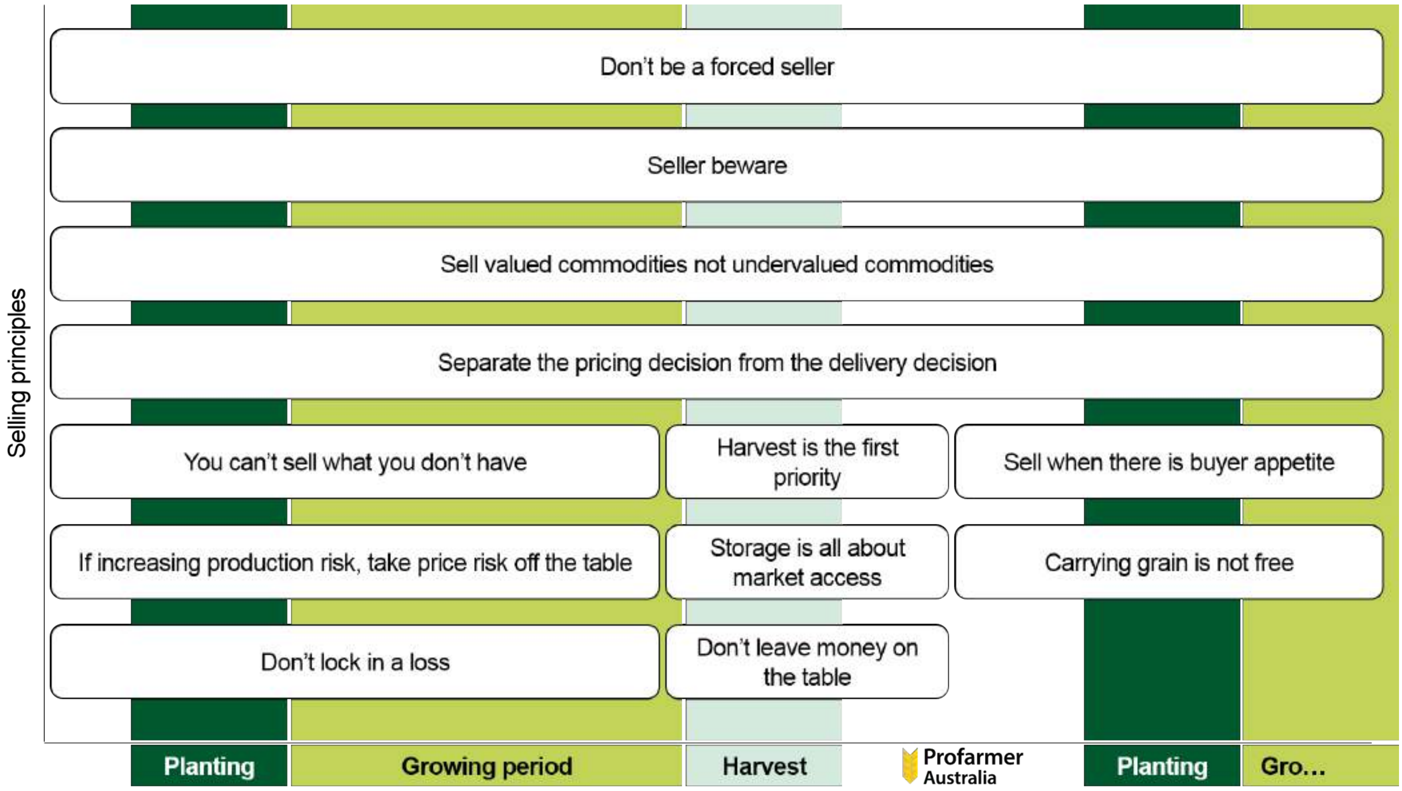


Figure 3: *Grower commodity selling principles timeline.*

The illustration demonstrates the key selling principles throughout the production cycle of a crop.]

Source: Profarmer Australia

15.1.2 Establish the business risk profile

Establishing a business risk profile helps growers determine when to sell: it allows growers to develop target price ranges for each commodity, and provides confidence to sell when the opportunity arises. Typical business circumstances and how to quantify the risks during the production cycle are described below (Figure 4).

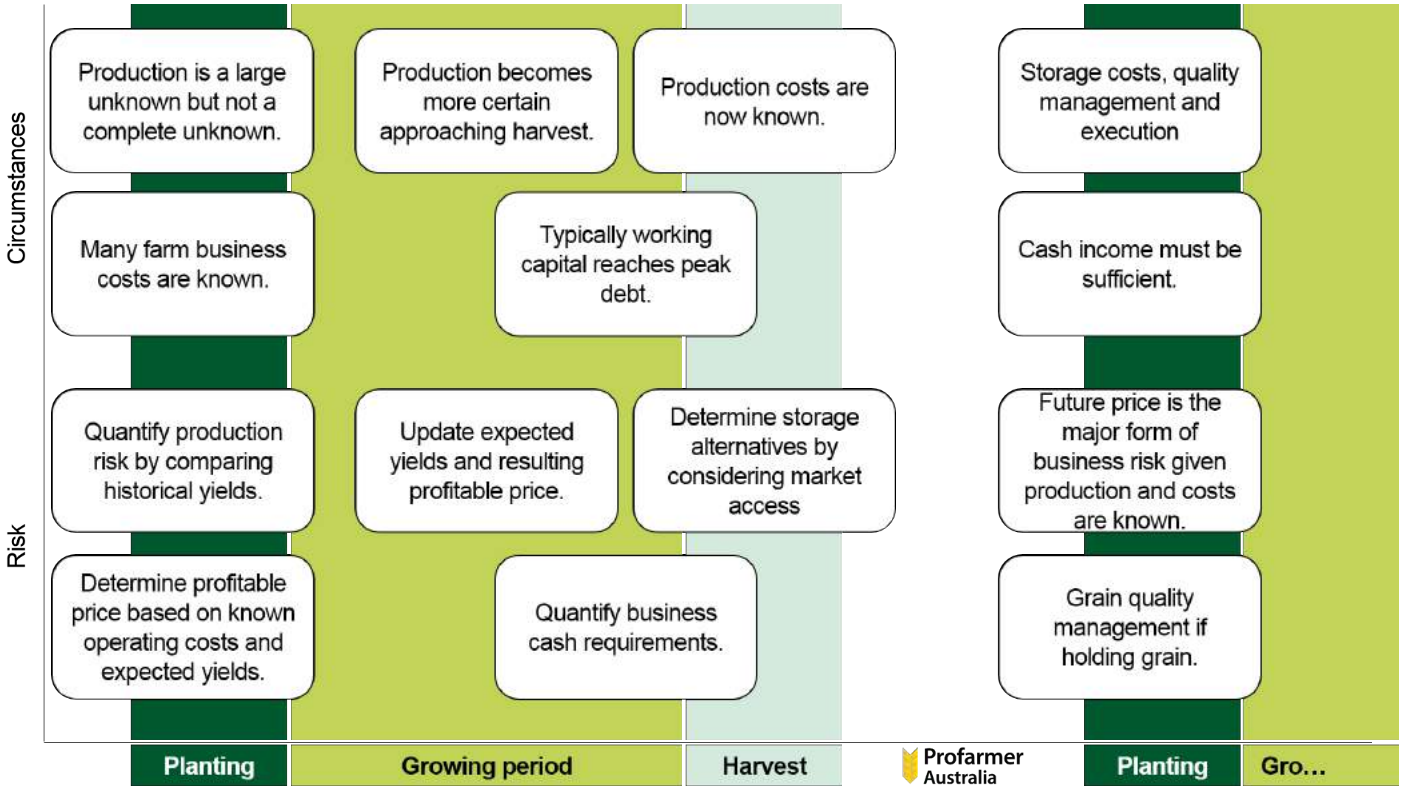


Figure 4: *Typical farm business circumstances and risk.*

When does a grower sell their grain? This decision making is dependent on:

- Does production risk allow sales? And what portion of production?
- Is the price profitable?
- Are business cash requirements being met?

Source: Profarmer Australia

Production risk profile of the farm

Production risk is the level of certainty around producing a crop and is influenced by location (climate, season and soil type), crop type, crop management, and the time of the year.

Principle: You can't sell what you don't have.

Therefore, don't increase business risk by over committing production. Establish a production risk profile (see Figure 5) by:

1. Collating historical average yields for each crop type and a below-average and above-average range
2. Assessing the likelihood of achieving the average, based on recent seasonal conditions and the seasonal outlook
3. Revising production outlooks as the season progresses.

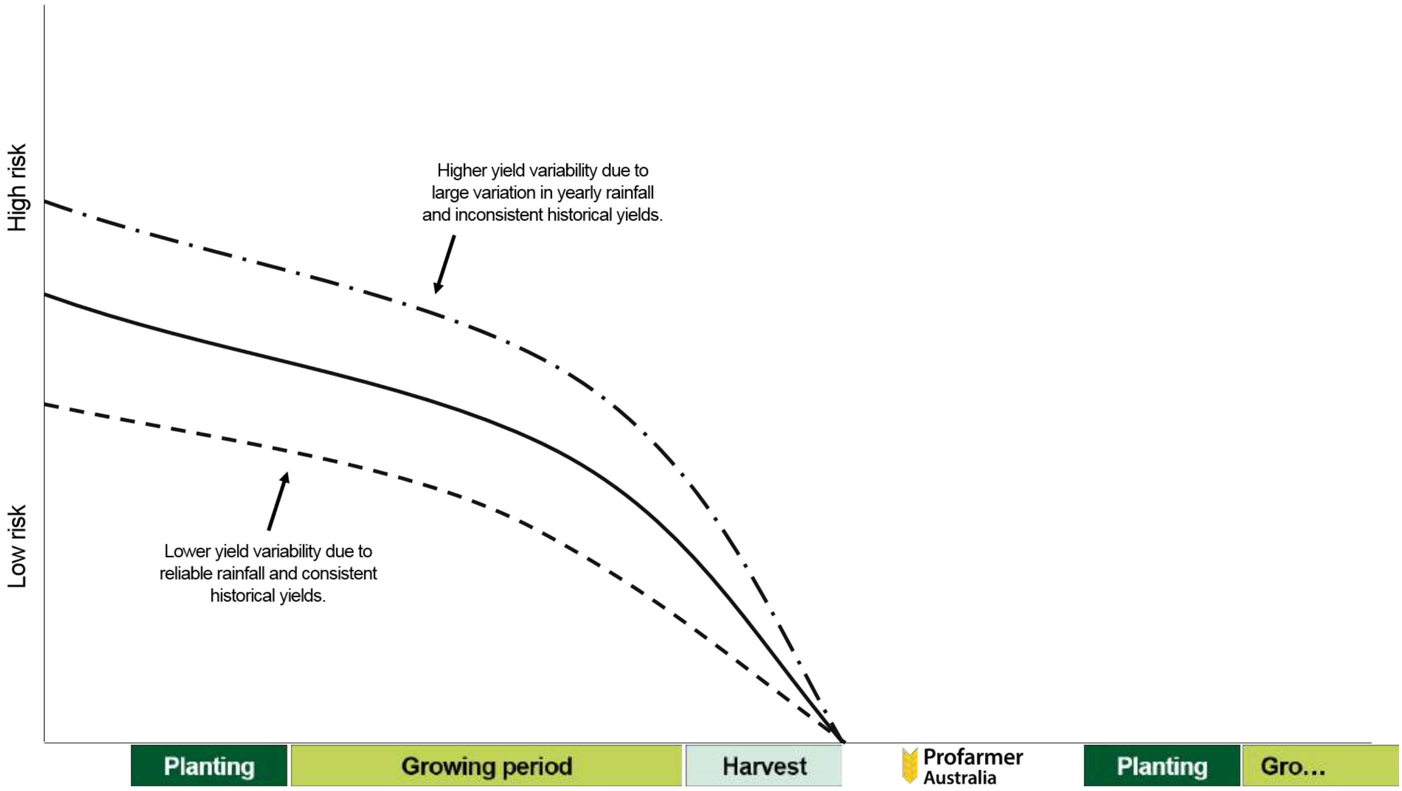


Figure 5: *Typical production risk profile of a farm operation.*

The quantity of crop grown is a large unknown early in the year however not a complete unknown. "You can't sell what you don't have" but it is important to compare historical yields to get a true indication of production risk. This risk reduces as the season progresses and yield becomes more certain. Businesses will face varying production risk level at any given point in time with consideration to rainfall, yield potential soil type, commodity etc

Source: Profarmer Australia

Establishing a target price

A profitable commodity target price is the cost of production per tonne plus a desired profit margin. It is essential to know the cost of production per tonne for the farm business, which means knowing all farming costs, both variable and fixed.

Principle: Don't lock in a loss.

If committing production ahead of harvest, ensure the price will be profitable. The steps needed to calculate an estimated profitable price is based on the total cost of production and a range of yield scenarios, as provided below (Figure 6).

Estimating Cost of Production - Barley		
Planted Area	1,200 ha	Step 1: Estimate your production potential. The more uncertain your production is, the more conservative the yield estimate should be. As yield falls, your cost of production per tonne will rise.
Estimated Yield	3.20 t/ha	
Estimated Production	3,840 t	
Fixed Costs		
Insurance and General Expenses	$100,000	Step 2: Attribute your fixed farm business costs. In this instance if 1,200ha reflects 1/3 of the farm enterprise, we have attributed 1/3 fixed costs. There are a number of methods for doing this (see M Klause "Farming Your Business") but the most important thing is that in the end all costs are accounted for.
Finance	$80,000	
Depreciation / Capital Replacement	$70,000	
Drawings	$60,000	
Other	$30,000	
Variable costs		
Seed and sowing	$42,000	Step 3: Calculate all the variable costs attributed to producing that crop. This can also be expressed as $ per ha x planted area.
Fertiliser and application	$144,000	
Herbicide and application	$72,000	
Insect / fungicide and application	$30,000	
Harvest costs	$48,000	
Crop insurance	$12,000	
Total Fixed and Variable costs	$688,000	
Per Tonne Equivalent (Total costs ÷ Estimated Production)	**$179 /t**	Step 4: Add together fixed and variable costs and divide by estimated production.
Per Tonne Costs		
Levies	$3 /t	Step 5: Add on the "per tonne" costs like levies and freight.
Cartage	$12 /t	
Freight to Port	$22 /t	
Total Per Tonne Costs	$37 /t	
Cost of production Port track equiv	$216.17	Step 6: Add the "per tonne" costs to the fixed and variable per tonne costs calculated at step 4. Add a desired profit margin to arrive at the port equivalent target profitable price.
Target profit (ie 20%)	$43.00	
Target price (port equiv)	**$259.17**	

Figure 6: *Calculating cost of production.*

Source: Profarmer Australia

MORE INFORMATION

GRDC's manual Farming the Business

Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables growers to time grain sales so that cash is available when required. This prevents having to sell grain below the target price to satisfy a need for cash.

Principle: Don't be a forced seller.

Be ahead of cash requirements to avoid selling in unfavourable markets.

Typical cash-flow to grow a crop are illustrated below (Figure 7 and Figure 8). Costs are incurred up front and during the growing season, with peak working capital debt incurred at or before harvest. Patterns will vary depending on circumstance and enterprise mix. The second figure demonstrates how managing sales can change the farm's cash balance.

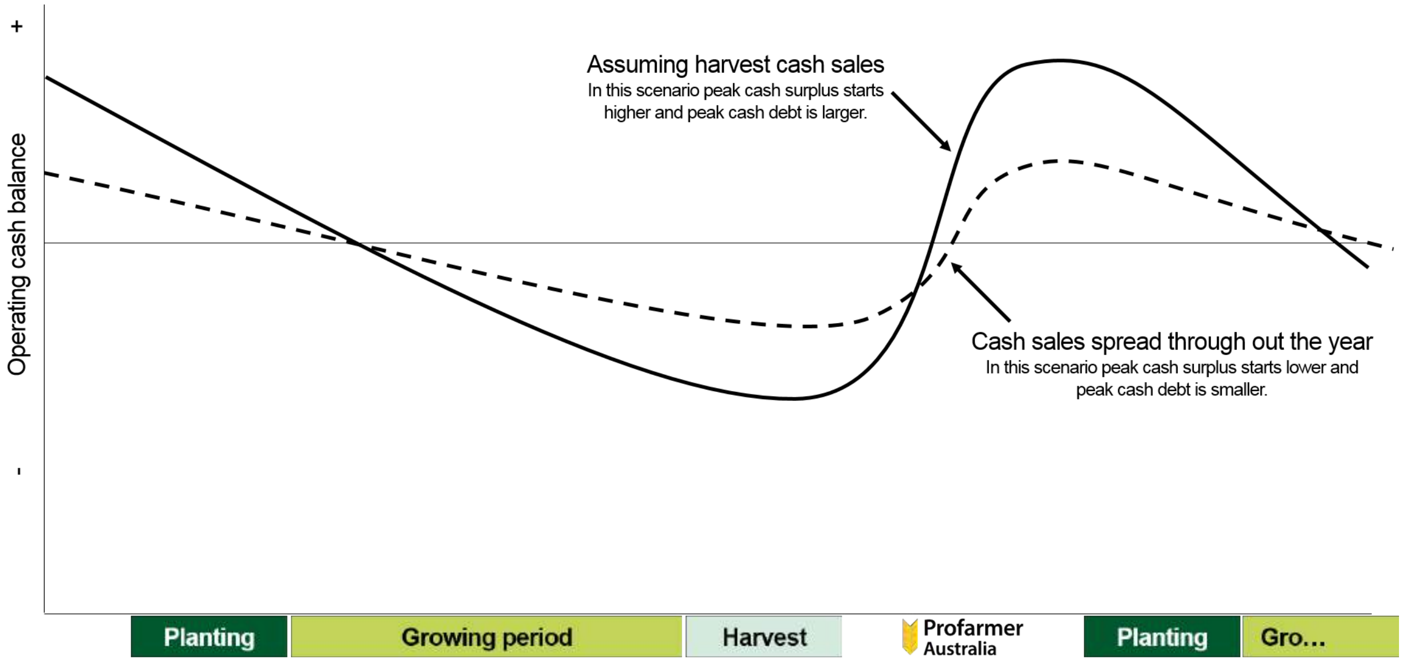


Figure 7: *Typical farm operating cash balance.*

The chart illustrates the operating cash flow of a typical farm assuming a heavy reliance on cash sales at harvest vs a farm business which spreads sales out throughout the year.

When harvest sales are more heavily relied upon costs are incurred during the season to grow the crop, resulting in peak operating debt levels at or near harvest. Hence at harvest there is often a cash injection required for the business. An effective marketing plan will ensure a grower is 'not a forced seller' in order to generate cash flow.

By spreading sales throughout the year a grower may not be as reliant on executing sales at harvest time in order to generate required cash flow for the business. This provides a greater ability to capture pricing opportunities in contrast to executing sales in order to fulfil cash requirements

Source: Profarmer Australia

The "when to sell" steps above result in an estimated production tonnage and the risk associated with that tonnage, a target price range for each commodity, and the time of year when cash is most needed.

15.1.3 Managing price

The first part of the selling strategy answers the question about when to sell and establishes comfort around selling a portion of the harvest.

The second part of the strategy, managing your price, addresses how to sell your crop.

Methods of price management

Pricing products provide varying levels of price risk coverage, but not all products are available for all crops (Table 1).

Table 1: *Pricing products provide varying levels of price risk coverage:*

	Description
Fixed price strategies	Fixed price strategies provide the most price certainty. Examples include cash, futures and bank swaps.
Floor price strategies	Floor price products limit price downside but provide exposure to future price upside. Examples include options on futures and floor price pool products.
Floating price strategies	Floating price strategies are subject to both price upside and down side. Examples include some pool products and doing nothing.

The diagram below provides a summary of where different methods of price management are suited for the majority of farm businesses..

Figure 8: *Price strategy timeline*

Different price strategies are more applicable through varying periods of the growing season. If selling in the forward market growers are selling something not yet grown, therefore the inherent production risk of the business increases. This means growers should achieve price certainty if committing tonnage ahead of harvest. Hence fixed or floor price products and strategies are favourable. Comparatively a floating price strategy can be effective in the harvest and post-harvest period.

Source: Profarmer Australia

Principle: If increasing production risk, take price risk off the table.

When committing to unknown production, price certainty should be achieved to avoid increasing overall business risk.

Principle: Separate the pricing decision from the delivery decision.

Most commodities can be sold at any time with delivery timeframes being negotiable, hence price management is not determined by delivery.

Fixed price

A fixed price is achieved via cash sales and/or selling a futures position (swaps) (Figure 9). It provides some certainty around expected revenue from a sale as the price is largely a known factor, except when there is a floating component in the price, e.g. a multi-grade cash contract with floating spreads or a floating-basis component on futures positions.

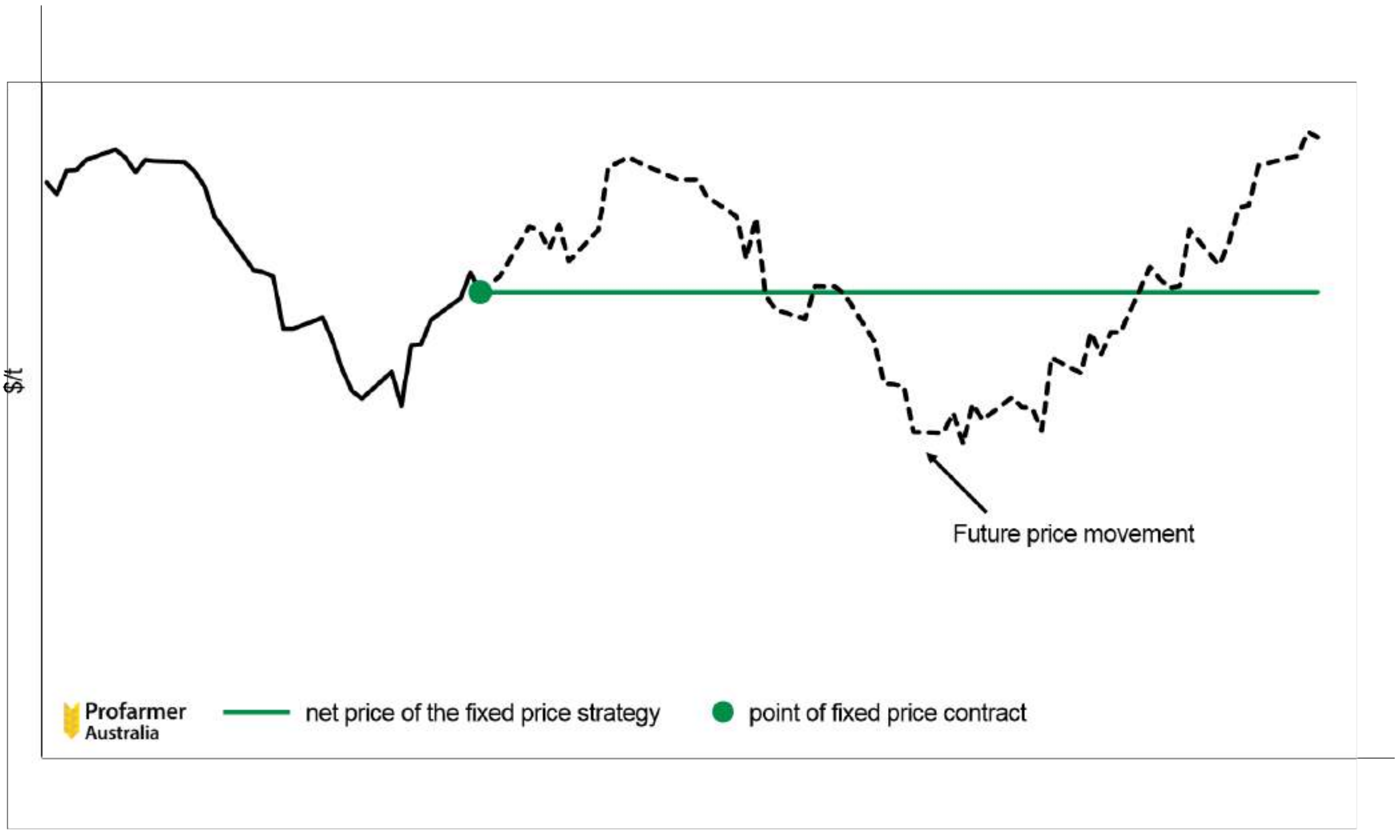


Figure 9: *Fixed price strategy.*

Fixed price product locks in price and provides certainty over what revenue will be generated regardless of future price movement.

Source: Profarmer Australia

Floor price

Floor-price strategies (Figure 10) can be achieved by utilising options on a relevant futures exchange (if one exists), or via a managed-sales program (i.e. a pool with a defined floor-price strategy) offered by a third party. This pricing method protects against potential future downside while capturing any upside. The disadvantage is that this kind of price 'insurance' has a cost, which adds to the farm's cost of production.

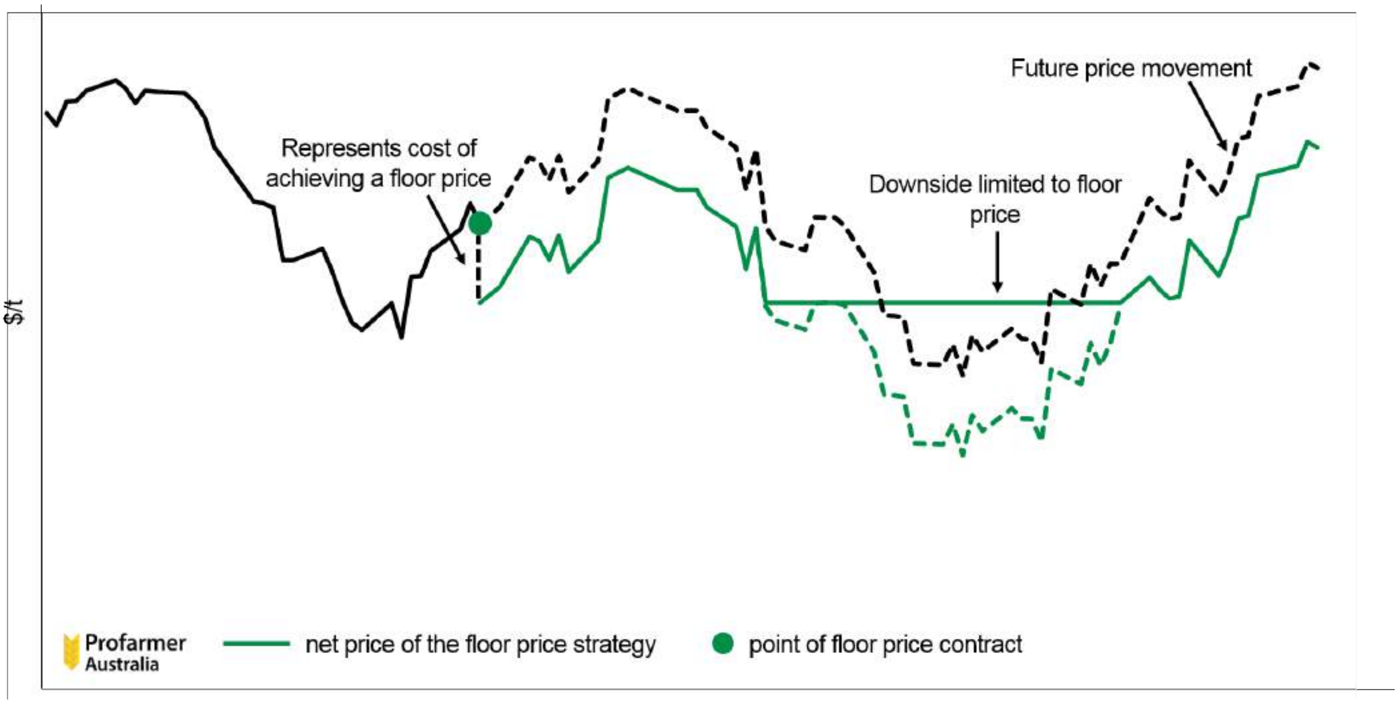


Figure 10: *Floor price strategy.*

A floor price strategy insures against potential future downside in price while allowing price grains in the event of future price rallies.

Source: Profarmer Australia

3. Floating price

Many of the pools or managed-sales programs are a floating price, where the net price received will move up and down with the future movement in price (Figure 11). Floating-price products provide the least price certainty and are best suited for use at or after harvest rather than before harvest.

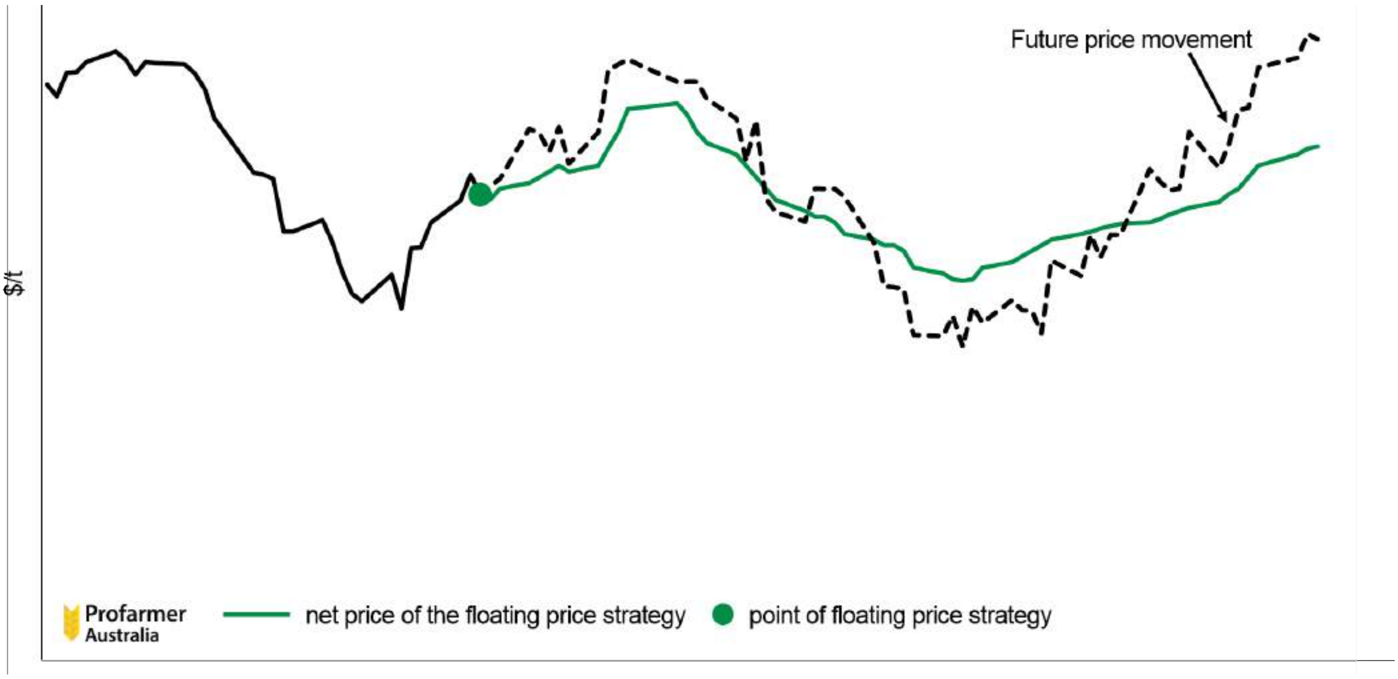


Figure 11: *Floating price strategy.*

A floating price will move to some extend with future price movements.

Source: Profarmer Australia

Having considered the variables of production for the crop to be sold, and how these fit against the different pricing mechanisms, the farmer may revise their selling strategy, taking the risks associated with each mechanism into account.

Fixed-price strategies include physical cash sales or futures products, and provide the most price certainty, but production risk must be considered.

Floor-price strategies include options or floor-price pools. They provide a minimum price with upside potential and rely less on production certainty, but cost more.

Floating-price strategies provide minimal price certainty, and so are best used after harvest.

15.1.4 Ensuring access to markets

Once the questions of when and how to sell are sorted out, planning moves to the storage and delivery of commodities to ensure timely access to markets and execution of sales. Planning where to store the commodity is an important component of ensuring the type of access to the market that is likely to yield the highest return (Figure 12).

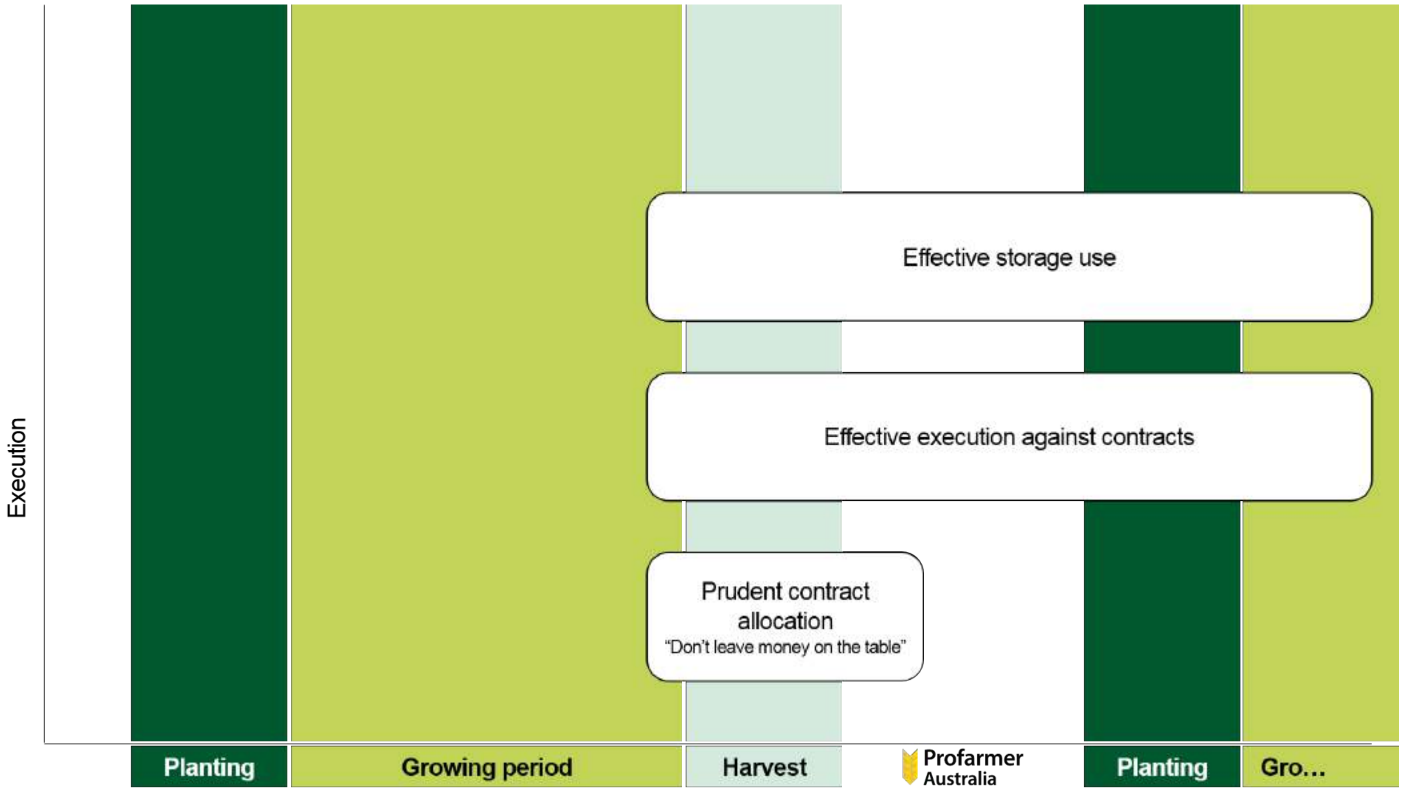


Figure 12: *Effective storage decisions.*

Note to figure thirteen: Once a grower has made the decision to sell the question becomes how they achieve this. The decision on how to sell is dependent upon

- The time of year determines the pricing method.
- Market access determines where to sell.
- Relative value determines what to sell.]

Source: Profarmer Australia

Storage and logistics

The return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access to maximise returns as well as harvest logistics.

Storage alternatives include variations of bulk handling, private off-farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity (Figure 13).

Principle: Harvest is the first priority.

During harvest, getting the crop into the bin is the most critical aspect of business success; hence storage, sale and delivery of grain should be planned well ahead of harvest to allow the grower to focus on the harvest itself.

Bulk export commodities requiring significant quality management are best suited to the bulk-handling system. Commodities destined for the domestic end-user market, (e.g. feedlot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on the farm requires prudent quality management to ensure that the grain is delivered to the agreed specifications. If not well planned and carried out, it can expose the business to high risk. Penalties for out-of-specification grain arriving at a buyer's weighbridge can be expensive, as the buyer has no obligation to accept it. This means the grower may have to incur the cost of taking the load elsewhere, and may also have to find a new buyer.

On-farm storage also requires that delivery is managed to ensure that the buyer receives the commodities on time and with appropriate weighbridge and sampling tickets.

Principle: Storage is all about market access.

Storage decisions depend on quality management and expected markets.

MORE INFORMATION

For more information on on-farm storage alternatives and economics refer to Section 13: Storage.

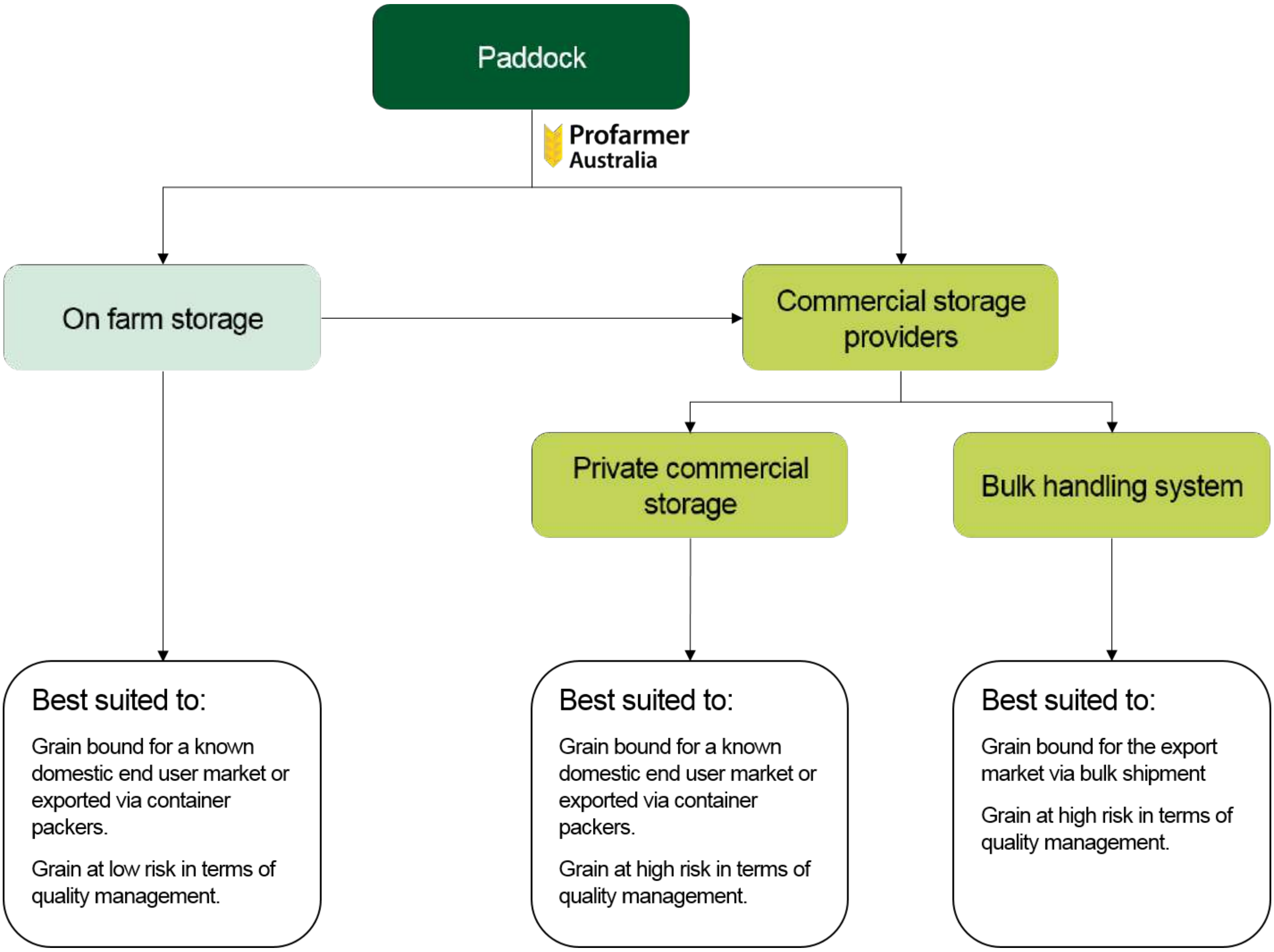


Figure 13: *Grain storage decision making.*

Decisions around storage alternatives of harvested commodities depend on market access and quality management requirements.]

Source: Profarmer Australia

Cost of carrying grain

Storing grain to access sales opportunities post-harvest invokes a cost to 'carry', or hold, the grain. Price targets for carried grain need to account for the cost of carrying it. Carrying costs are typically $3–4/t per month and consist of:

- Monthly storage fee charged by a commercial provider (typically ~$1.50–2.00/t)
- Monthly interest associated with having wealth tied up in grain rather than available as cash or for paying off debt (~$1.50–$2.00/t, depending on the price of the commodity and interest rates)

The price of carried grain therefore needs to be $3–4/t per month higher than the price offered at harvest (Figure 14).

The cost of carrying also applies to grain stored on the farm, as it must cover the cost of the capital invested in the farm storage, plus the interest component. A reasonable assumption is a cost of $3–4/t per month for on-farm storage.

Principle: Carrying grain is not free.

The cost of carrying grain needs to be accounted for if holding it for sale after harvest is part of the selling strategy. Therefore, if selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example, in the case of a March sale of $700/t + $5/t carrying per month, and for March –June delivery on the buyer's call, the contract delivered in June would generate revenue of $715/t delivered.

Figure 14: *Cash values vs cash adjusted for the cost of carry.*

If selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example on the case of a March sale of canola for March –June delivery on the buyers call at $250/t + $3/t carry per month, if delivered in June this contract would generate revenue of $259/t delivered.

Source: Profarmer Australia

Optimising farm-gate returns involves planning the appropriate storage strategy for each commodity so as to improve market access and ensure that carrying costs are covered in the price received.

15.1.5 Converting tonnes into cash

This section provides guidelines for converting the selling and storage strategy into cash by effective execution of sales.

Set up the toolbox

Selling opportunities can be captured when they arise by assembling the necessary tools in advance. The toolbox for converting tonnes of grain into cash includes the following.

1. Timely information—this is critical for awareness of selling opportunities and includes:
   - Market information provided by independent parties
   - Effective price discovery including indicative bids, firm bids and trade prices
   - Other market information pertinent to the particular commodity
2. Professional services—grain-selling professional services and cost structures vary considerably. An effective grain-selling professional will put their clients' best interests first by not having conflicts of interest and by investing time in the relationship. A better return on investment for the farm business is achieved through higher farm-gate prices, which are obtained by accessing timely information, and being able to exploit the seller's greater market knowledge and greater market access
3. Futures account and a bank-swap facility—these accounts provide access to global futures markets. Hedging futures markets is not for everyone; however, strategies which utilise exchanges such as the Chicago Board of Trade (CBOT) can add significant value.

MORE INFORMATION

Access to buyers, brokers, agents, products and banks through Grain Trade Australia

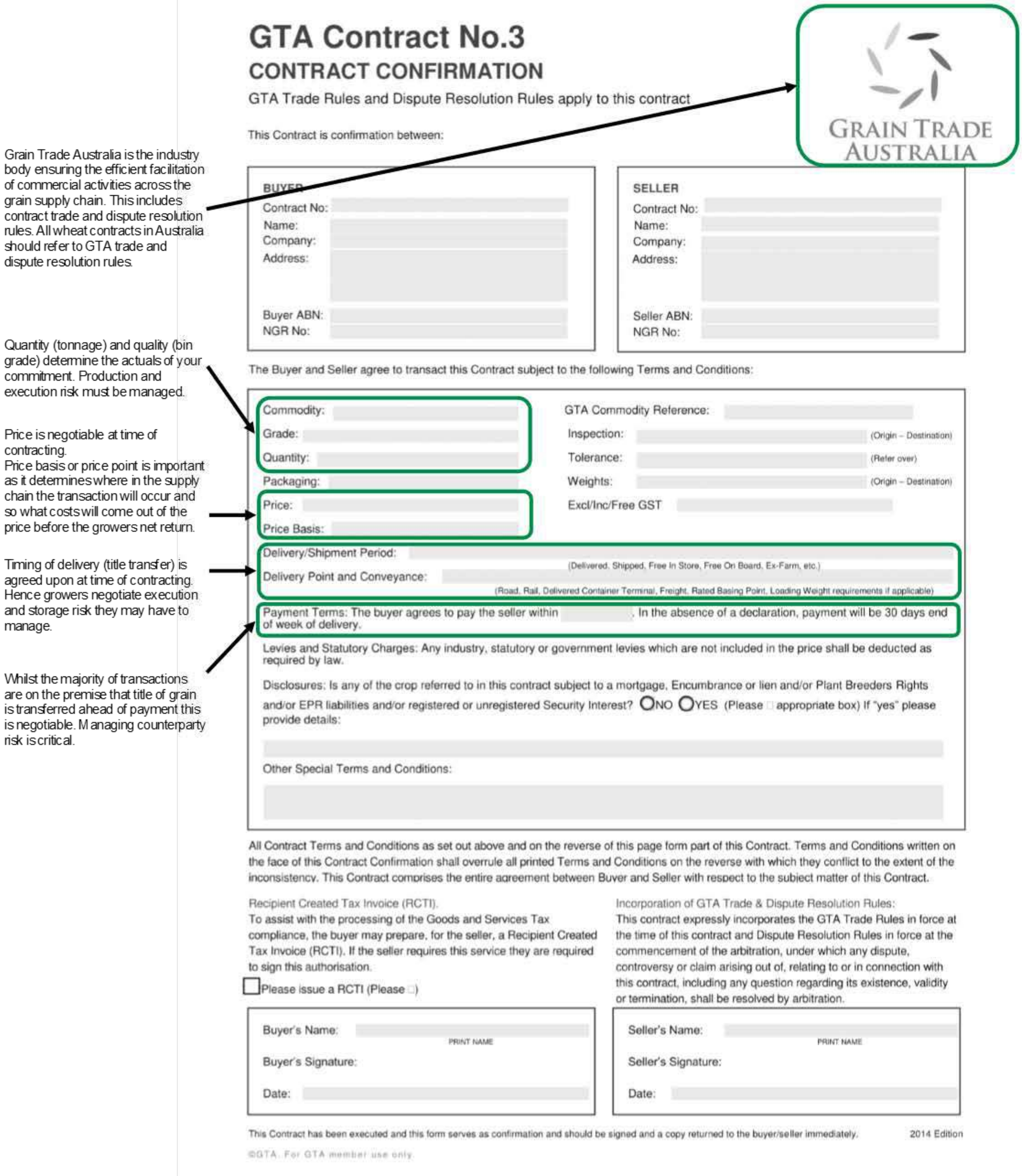
Commodity futures brokers

ASX, Find a futures broker

How to sell for cash

Like any market transaction, a cash–grain transaction occurs when a bid by the buyer is matched by an offer from the seller. Cash contracts are made up of the following components, with each component requiring a level of risk management (Figure 15):

- Price—future price is largely unpredictable, so devising a selling plan to put current prices into the context of the farm business is critical to managing price risk
- Quantity and quality—when entering a cash contract, you are committing to deliver the nominated amount of grain at the quality specified, so production and quality risks must be managed
- Delivery terms—the timing of the title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end-users, it relies on prudent execution management to ensure delivery within the contracted period
- Payment terms—in Australia, the traditional method of contracting requires title on the grain to be transferred ahead of payment, so counterparty risk must be managed



Grain Trade Australia is the industry body ensuring the efficient facilitation of commercial activities across the grain supply chain. This includes contract trade and dispute resolution rules. All wheat contracts in Australia should refer to GTA trade and dispute resolution rules.

Quantity (tonnage) and quality (bin grade) determine the actuals of your commitment. Production and execution risk must be managed.

Price is negotiable at time of contracting.
Price basis or price point is important as it determines where in the supply chain the transaction will occur and so what costs will come out of the price before the growers net return.

Timing of delivery (title transfer) is agreed upon at time of contracting. Hence growers negotiate execution and storage risk they may have to manage.

Whilst the majority of transactions are on the premise that title of grain is transferred ahead of payment this is negotiable. Managing counterparty risk is critical.

GTA Contract No.3
CONTRACT CONFIRMATION
GTA Trade Rules and Dispute Resolution Rules apply to this contract

GRAIN TRADE AUSTRALIA

This Contract is confirmation between:

BUYER	SELLER
Contract No:	Contract No:
Name:	Name:
Company:	Company:
Address:	Address:
Buyer ABN:	Seller ABN:
NGR No:	NGR No:

The Buyer and Seller agree to transact this Contract subject to the following Terms and Conditions:

Commodity: GTA Commodity Reference:
Grade: Inspection: (Origin – Destination)
Quantity: Tolerance: (Refer over)
Packaging: Weights: (Origin – Destination)
Price: Excl/Inc/Free GST
Price Basis:
Delivery/Shipment Period: (Delivered, Shipped, Free In Store, Free On Board, Ex-Farm, etc.)
Delivery Point and Conveyance: (Road, Rail, Delivered Container Terminal, Freight, Rated Basing Point, Loading Weight requirements if applicable)
Payment Terms: The buyer agrees to pay the seller within . In the absence of a declaration, payment will be 30 days end of week of delivery.
Levies and Statutory Charges: Any industry, statutory or government levies which are not included in the price shall be deducted as required by law.
Disclosures: Is any of the crop referred to in this contract subject to a mortgage, Encumbrance or lien and/or Plant Breeders Rights and/or EPR liabilities and/or registered or unregistered Security Interest? NO YES (Please appropriate box) If "yes" please provide details:
Other Special Terms and Conditions:

All Contract Terms and Conditions as set out above and on the reverse of this page form part of this Contract. Terms and Conditions written on the face of this Contract Confirmation shall overrule all printed Terms and Conditions on the reverse with which they conflict to the extent of the inconsistency. This Contract comprises the entire agreement between Buyer and Seller with respect to the subject matter of this Contract.

Recipient Created Tax Invoice (RCTI).
To assist with the processing of the Goods and Services Tax compliance, the buyer may prepare, for the seller, a Recipient Created Tax Invoice (RCTI). If the seller requires this service they are required to sign this authorisation.
Please issue a RCTI (Please)

Incorporation of GTA Trade & Dispute Resolution Rules:
This contract expressly incorporates the GTA Trade Rules in force at the time of this contract and Dispute Resolution Rules in force at the commencement of the arbitration, under which any dispute, controversy or claim arising out of, relating to or in connection with this contract, including any question regarding its existence, validity or termination, shall be resolved by arbitration.

Buyer's Name: PRINT NAME	Seller's Name: PRINT NAME
Buyer's Signature:	Seller's Signature:
Date:	Date:

This Contract has been executed and this form serves as confirmation and should be signed and a copy returned to the buyer/seller immediately. 2014 Edition

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Figure 15: *Typical cash contracting as per Grain Trade Australia standards.*

Source: Grain Trade Australia

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. Figure 16 depicts the terminology used to describe these points and the associated costs to come out of each price before growers receive their net return.

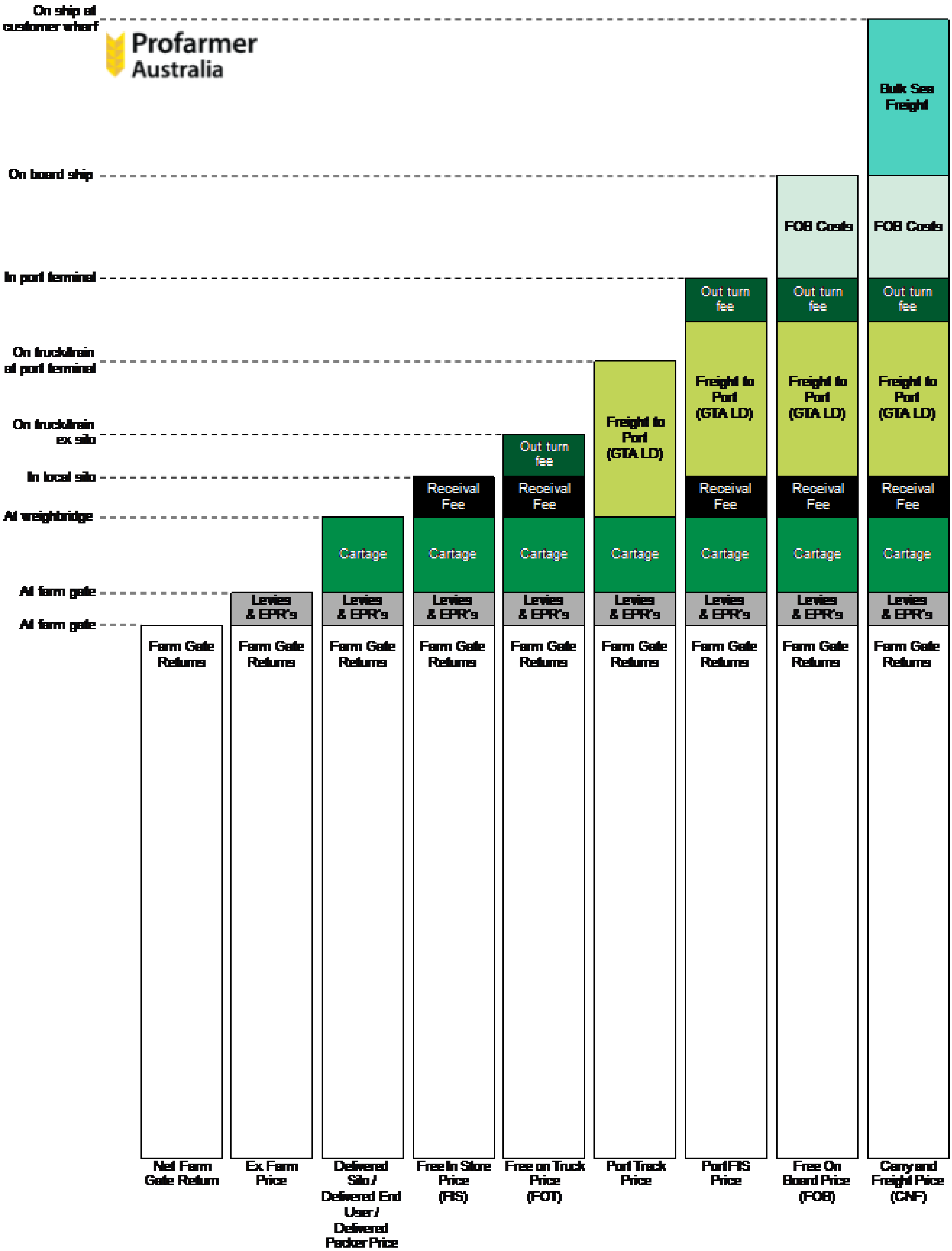

Figure 16: *Costs and pricing points throughout the supply chain*

Source: Profarmer Australia

MORE INFORMATION

Grain Trade Australia, A guide to taking out grain contracts

Grain Trade Australia, Trading standards

GrainTransact Resource Centre

GrainFlow

Emerald Grain

Clear Grain Exchange, Getting started

Clear Grain Exchange, Terms and conditions

GTA, Managing counterparty risk

Clear Grain Exchange's title transfer model

GrainGrowers, Managing risk in grain contracts

Leo Delahunty, Counterparty risk: A producer's perspective

Cash sales generally occur through three methods:

- **Negotiation via personal contact**—traditionally prices are posted as a public indicative bid. The bid is then accepted or negotiated by a grower with the merchant or via an intermediary. This method is the most common and is available for all commodities.
- **Accepting a public firm bid**—cash prices in the form of public firm bids are posted during harvest and for warehoused grain by merchants on a site basis. Growers can sell their parcel of grain immediately by accepting the price on offer via an online facility and then transfer the grain online to the buyer. The availability of this option depends on location and commodity.
- **Placing an anonymous firm offer**—growers can place a firm offer price on a parcel of grain anonymously and expose it to the entire market of buyers, who then bid on it anonymously using the Clear Grain Exchange, which is an independent online exchange. If the offer and bid match, the particulars of the transaction are sent to a secure settlement facility, although the title on the grain does not transfer from the grower until they receive funds from the buyer. The availability of this option depends on location and commodity. Anonymous firm offers can also be placed to buyers by an intermediary acting on behalf of the grower. If the grain sells, the buyer and seller are disclosed to each counterparty.

Counterparty risk

Most sales involve transferring the title on the grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: Seller beware.

There is not much point selling for an extra $5/t if the grower doesn't get paid.

Counterparty risk management includes:

- Dealing only with known and trusted counterparties
- Conducting a credit check (banks will do this) before dealing with a buyer they are unsure of
- Selling only a small amount of grain to unknown counterparties
- Considering credit insurance or a letter of credit from the buyer
- Never delivering a second load of grain if payment has not been received for the first
- Not parting with the title before payment, or requesting and receiving a cash deposit of part of the value ahead of delivery. Payment terms are negotiated at time of contracting. Alternatively, the Clear Grain Exchange provides secure settlement whereby the grower maintains title on the grain until they receive payment, and then title and payment are settled simultaneously

Above all, act commercially to ensure the time invested in implementing a selling strategy is not wasted by poor management of counterparty risk. Achieving $5/t more on paper and not getting paid is a disastrous outcome.

Relative values

Grain-sales revenue is optimised when selling decisions are made in the context of the whole farming business. The aim is to sell each commodity when it is priced well, and to hold commodities that are not well priced at any given time. That is, give preference to the commodities with the highest relative value. This achieves price protection for the overall revenue of the farm business and enables more flexibility to a grower's selling program while achieving the business goal of reducing overall risk.

Principle: Sell valued commodities, not undervalued commodities.

If one commodity is priced strongly relative to another, focus sales there. Don't sell the cheaper commodity for a discount. For example, a farmer with wheat and barley to sell would sell the one that is getting the better price relative to the other, and hold the other for the meantime (see Figure 17).

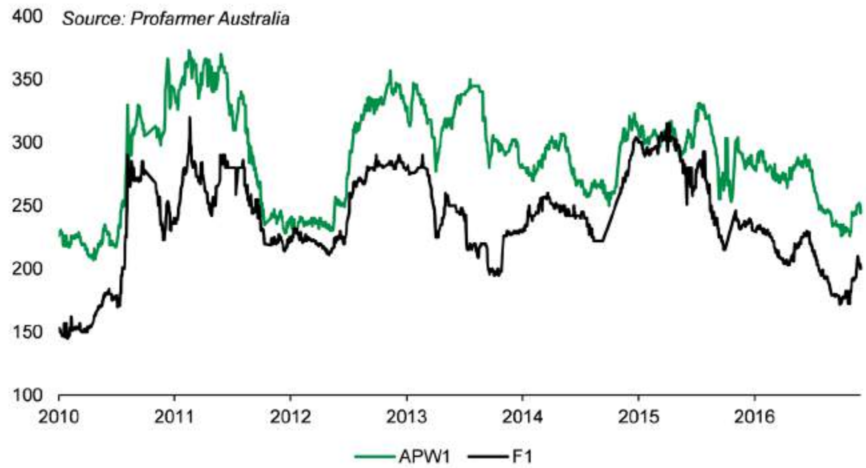

Figure 17: *Wheat vs Barley Kwinana*

Source: Profarmer Australia

If the decision has been made to sell wheat, wheat sold on the Chicago Board of Trade (CBOT) may be the better choice if the futures market is showing better value than the cash market

Contract allocation

Contract allocation means choosing which contracts to allocate your grain against come delivery time. Different contracts will have different characteristics (e.g. price, premiums-discounts, oil bonuses), and optimising your allocation reflects immediately on your bottom line.

Principle: Don't leave money on the table.

Contract allocation decisions don't take long, and can be worth thousands of dollars to your bottom line.

To achieve the best average price for their crop growers should:

- Allocate lower grades of grain to contracts with the lowest discounts
- Allocate higher grades of grain to contracts with the highest premiums (Figure 18).

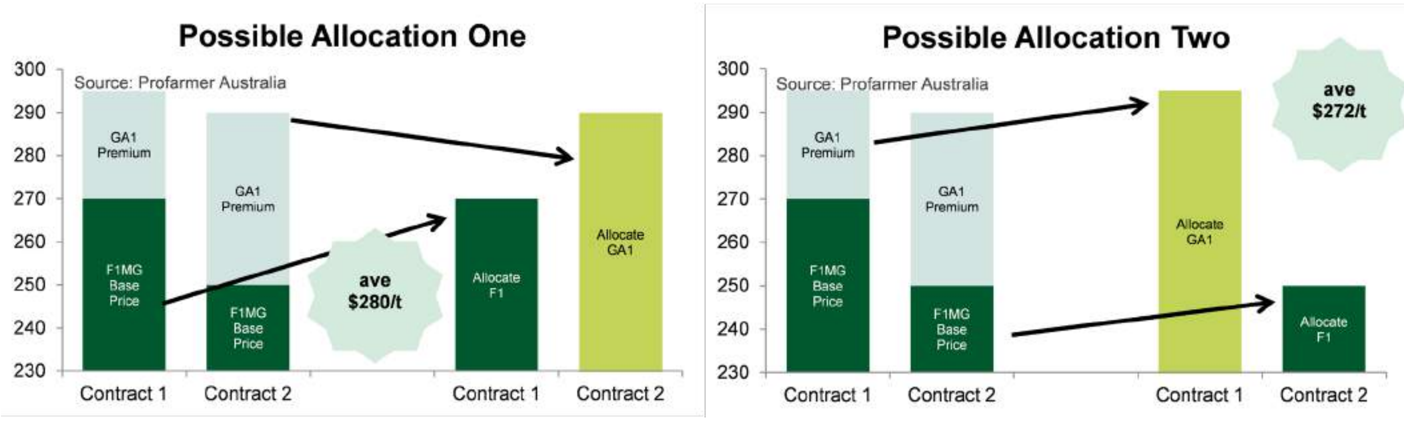

Figure 18: *Barley contract allocation example.*

Source: Profarmer Australia

Read market signals

The appetite of buyers to buy a particular commodity will differ over time depending on market circumstances. Ideally growers should aim to sell their commodity when buyer appetite is strong, and stand aside from the market when buyers are not very interested.

Principle: Sell when there is buyer appetite.

When buyers are chasing grain, growers have more market power to demand the price they want.

Buyer appetite can be monitored by:

- The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate that buyer appetite is strong. However, if one buyer is offering $5/t above the next best bid, it may mean that cash prices are susceptible to falling $5/t as soon as that buyer satisfies their appetite
- Monitoring actual trades against public indicative bids. When trades are occurring above indicative public bids it may indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids. The chart below plots actual trade prices on the Clear Grain Exchange against the best public indicative bid on the day

The selling strategy is converted to maximum business revenue by:

- Ensuring timely access to information, advice and trading facilities
- Using different cash-market mechanisms when appropriate
- Minimising counterparty risk by conducting effective due diligence
- Understanding relative value and selling commodities when they are priced well
- Thoughtful contract allocation
- Reading market signals to extract value from the market or to prevent selling at a discount

15.2 Western barley: market dynamics and execution

15.2.1 Price determinants

Australia is a relatively small player in terms of world barley production, contributing about 5–6% of global barley production. However, in terms of world trade, Australia is a major player, exporting 50–70% of the national barley crop, which accounts for about 20% of global wheat trade.

The consumption and production of barley globally has declined over the last 30 years as the market shifts towards other commodities (Figure 19). The demand that remains, however, represents consumers who are more reluctant to shift to other commodities, which means that global demand tends to be relatively inelastic. This is particularly true for malting barley, which cannot be substituted. This inelasticity means that at times when production is uncertain, malt barley can trade at strong premiums to other commodities and to feed barley, as the market competes to obtain what is perceived to be limited supply.

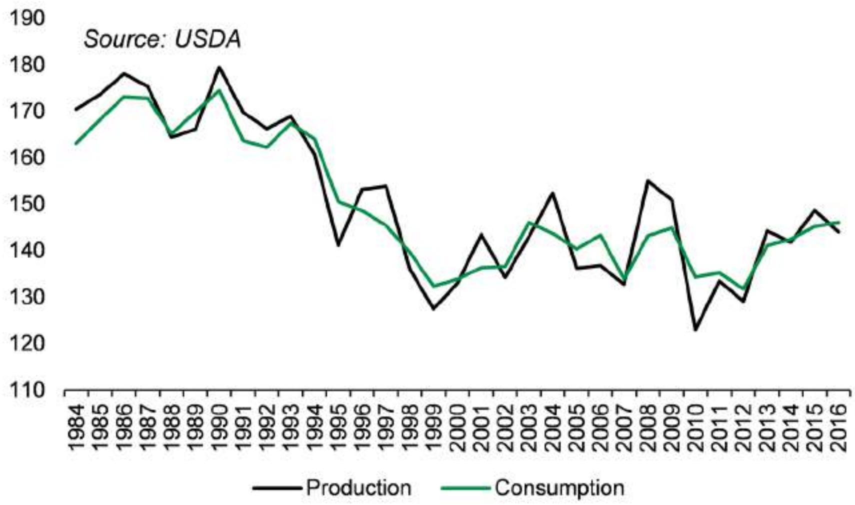

Figure 19: *Global barley production vs consumption (Million tonnes).*

WA is Australia's largest barley export state, exporting 80–90% of its production each year. The Middle East, particularly Saudi Arabia, is a very important market for WA feed barley, along with Japan and, more recently, China. However, demand from China tends to be heavily influenced by local feed-grain policies, so it can be highly variable from one season to another.

International trade prices are often the best indicators of where Australian barley values will trade. Barley values are also influenced by price relativities to wheat.

Because the focus on barley growing in WA is the export market, it is important that growers wanting to maximise prices understand worldwide barley production (Figure 20). Due to the export WA focus, the timing of harvest in major exporting and importing countries has a considerable influence on prices.

Decile charts are also useful, as they provide an indication of how current values are performing relative to historical values. A decile of eight or above indicates that current values are in the top 20% of historical price observations (Figure 21 and Figure 22).

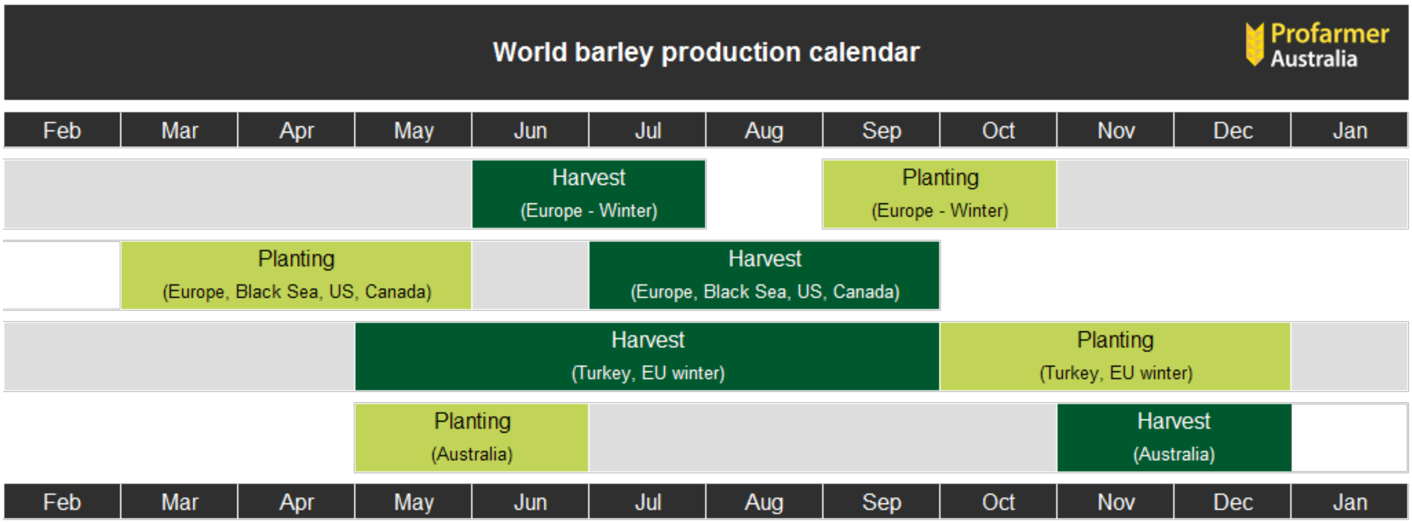

Figure 20: *World barley production calendar.*

Source: Profarmer Australia

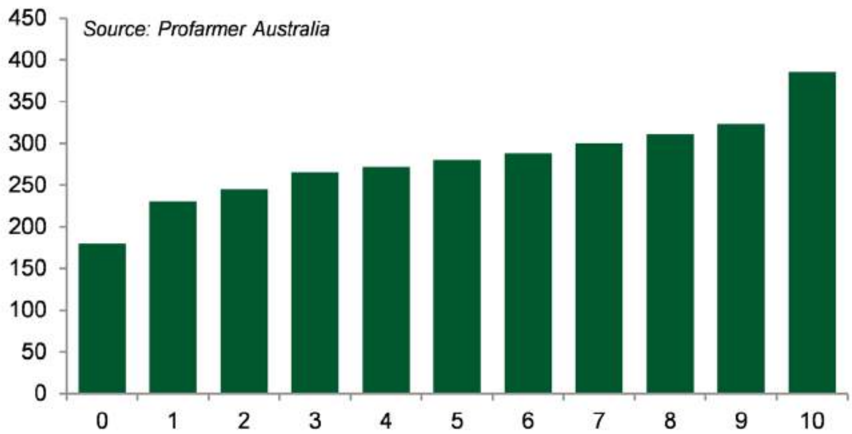

Figure 21: *: Kwinana Malt Barley Deciles.*

decile charts such as this provide us an indication of how current values are performing relative to historical values. For example a decile of 8 or above indicates current values are in the top 20% of historical price observations.

Source: Profarmer Australia

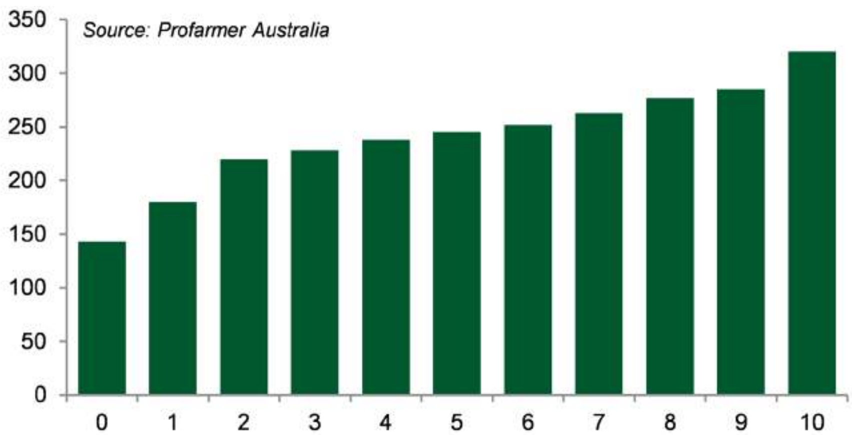

Figure 22: *: Kwinana Feed Barley Deciles.*

Note to figure twenty three: decile charts such as this provide us an indication of how current values are performing relative to historical values. For example a decile of 8 or above indicates current values are in the top 20% of historical price observations.

Source: Profarmer Australia

15.2.2 Ensuring market access

Given the majority of barley in WA is exported in bulk for human consumption, the most cost-effective pathway to get grain to off-shore customers is usually via the bulk-handling system. The bulk-storage provider should gain scale efficiencies when moving the bulk commodity grades such as Malt 1 and F1 feed barley.

Market Destinations - Barley - 5 year averages

	Western Australia		National Total	
	Implied tonnes	% of production	Implied tonnes	% of production
Exports	2.0 Mt	80%	5.0 Mt	60%
Domestic Use	0.5 Mt	20%	3.5 Mt	40%

Source: Australian Crop Forecasters

Figure 23: *Market destinations for Australian barley.*

Source: Australian Crop Forecasters

Although most WA barley will be stored and sold from within a bulk-handling system, private commercial storage and on-farm storage are a reasonable alternative for accessing container-export and domestic end-user markets.

Domestic consumers in WA demand a relatively small proportion of the crop, but growers who are well positioned to service these markets they can at times gain premiums over the bulk-export market. As private commercial or on-farm storage can be a more effective method of accessing this market, it is worth considering when planning sales (Figure 23).

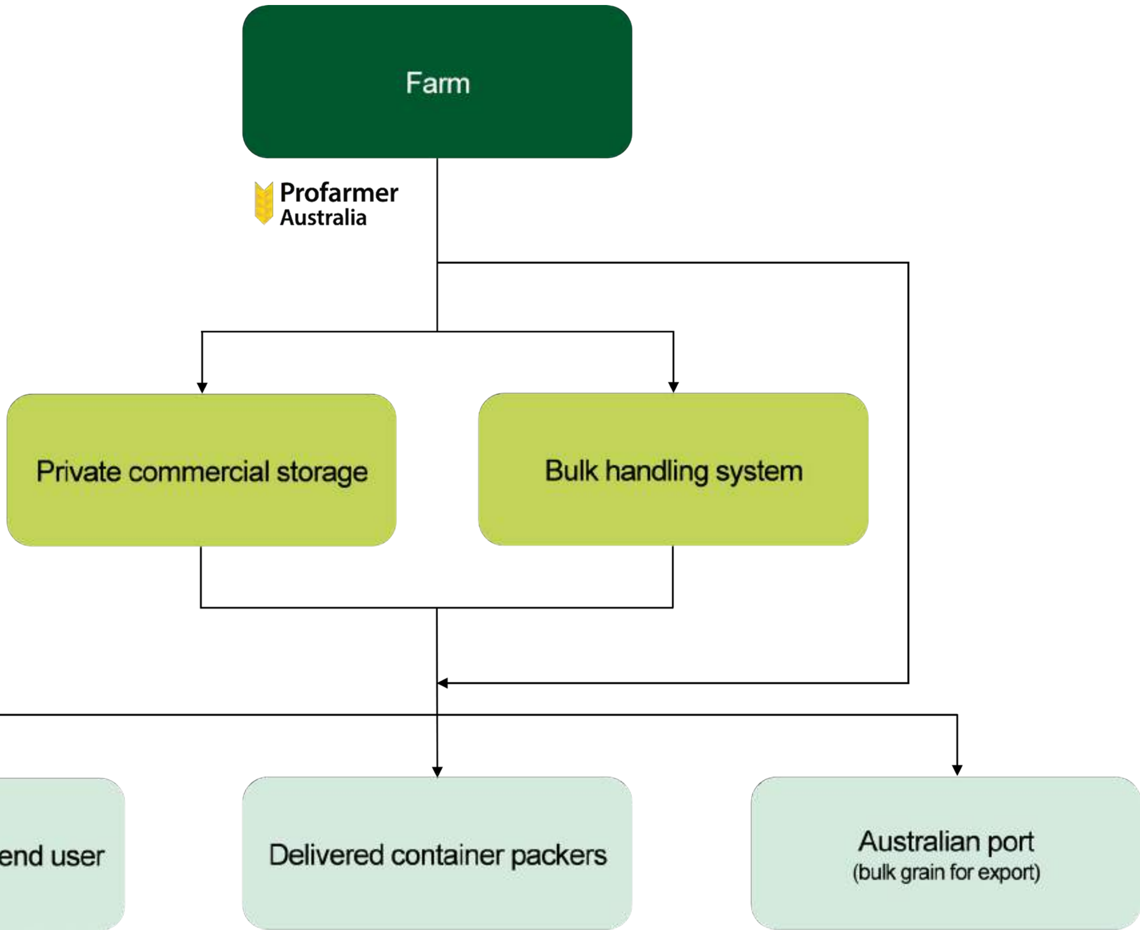

Figure 24: *Australian Supply chain flow.*

Storage decisions should be determined by assessing market access

15.2.3 Converting tonnes into cash

Knowing where the WA barley crop is likely to end up will help refine a grower's selling and logistics decisions. Broadly there are two customer types:

- Those who require a consistent supply of reliable quality grain in regular intervals regardless of the time of year.
- Those who are opportunistic buyers, based on price, and are able to manage the quality inconsistency that is associated with regularly switching suppliers.

As a result, the appetite to accumulate WA barley often peaks during and shortly after harvest, as a surge in demand kicks in to make the most of more abundant supply, and to realise shipping cost savings immediately after harvest. This is particularly true for malt barley, where demand is often very steady and buyers will seek to secure their requirements while there is the most certainty of availability.

What does this mean for a WA grower? Demand is generally strongest for WA barley during the harvest period when the number of buyers bidding for barley increases. Due to the extra bid liquidity at harvest, most grower selling strategies should encompass some harvest sales.

The key to effectively executing harvest sales is determining which grades to sell and which grades to hold. Malting barley grades generally trade at stronger levels during harvest. This is because consumers of these grades require consistent quality and, often, quantity, so they tend to accumulate their requirements before harvest and at harvest to ensure their supply while it is available. This appetite tends to push up the price premium for malting barley grades over the base Feed F1, making them a more attractive harvest sell. These grades are riskier to hold for post-harvest sales, as once the buyers have their requirements covered, prices tend to drop towards F1 levels as buyers begin to drop out of the market.

Typically, relative to malt barley, feed barley won't perform as strongly. However, the gap between feed and malting grades tends to close up after harvest, making feed barley lower risk and more desirable to hold for post-harvest sales (Figure 25). Premiums for malt barley over feed barley tend to widen from shortly before to shortly after harvest, but narrow in the post-harvest market as buyer appetite and liquidity in the malt barley market drops off.

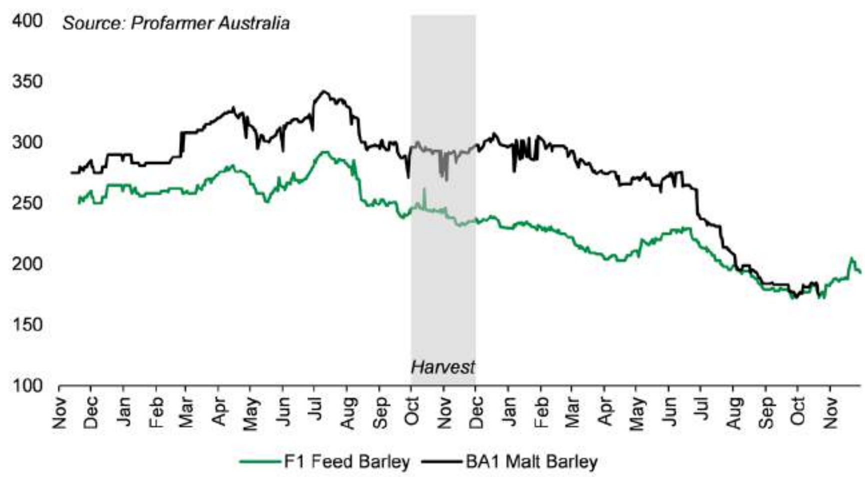

Figure 25: *Kwinana malt vs feed values.*

Premiums for malt barley over feed tend to widen shortly before, during and after harvest, but narrow in the post-harvest market as buyer appetite and liquidity in the malt barley market drops off.

Source: Profarmer Australia

15.2.4 Risk management tools

An Australian cash price is made up of three components: futures, foreign exchange, and basis. Each component has an impact on price, e.g. a higher futures and basis, and a lower exchange rate will result in a higher Australian grain price. Several barley futures contract types exist, including:

- ASX Eastern Australia Feed Barley—for feed barley of Australian origin, deliverable in New South Wales and Victoria, and is a minimum of GTA Feed Barley (F1) or equivalent
- ICE Western Canada Feed Barley—the grade of barley deliverable at par against the barley futures contract is No. 1 Canada western barley, which is a grade generally used for livestock feed

It is important to note liquidity in barley futures markets can be low, and this can create extra market risk for participants. For example, Euronext stopped running a European malting barley futures contract due to a lack of liquidity. Because of this, some participants choose to look at other futures markets, e.g. CBOT for wheat, to manage barley price risk. Australian barley and wheat values have a high correlation, hence, to some extent, a CBOT wheat futures contract can be used to hedge price risk against barley production.

Current and past research

Project Summaries

As part of a continuous investment cycle each year the Grains Research and Development Corporation (GRDC) invests in several hundred research, development and extension and capacity building projects. To raise awareness of these investments the GRDC has made available summaries of these projects.

These project summaries have been compiled by GRDC's research partners with the aim of raising awareness of the research activities each project investment.

The GRDC's project summaries portfolio is dynamic: presenting information on current projects, projects that have concluded and new projects which have commenced. It is updated on a regular basis.

The search function allows project summaries to be searched by keywords, project title, project number, theme or by GRDC region (i.e. Northern, Southern or Western Region).

Where a project has been completed and a final report has been submitted and approved a link to a summary of the project's final report appears at the top of the page.

The link to Project Summaries is https://grdc.com.au/research/reports

Final Report Summaries

In the interests of raising awareness of GRDC's investments among growers, advisers and other stakeholders, the GRDC has available final reports summaries of projects.

These reports are written by GRDC research partners and are intended to communicate a useful summary as well as present findings of the research activities from each project investment.

The GRDC's project portfolio is dynamic with projects concluding on a regular basis.

In the final report summaries there is a search function that allows the summaries to be searched by keywords, project title, project number, theme or GRDC Regions. The advanced options also enables a report to be searched by recently added, most popular, map or just browse by agro-ecological zones.

The link to the Final Report Summaries is http://finalreports.grdc.com.au/final_reports.php

Online Farm Trials

The Online Farm Trials project brings national grains research data and information directly to the grower, agronomist, researcher and grain industry community through innovative online technology. Online Farm Trials is designed to provide growers with the information they need to improve the productivity and sustainability of their farming enterprises.

Using specifically developed research applications, users are able to search the Online Farm Trials database to find a wide range of individual trial reports, project summary reports and other relevant trial research documents produced and supplied by Online Farm Trials contributors.

The Online Farm Trials website collaborates closely with grower groups, regional farming networks, research organisations and industry to bring a wide range of crop research datasets and literature into a fully accessible and open online digital repository.

Individual trial reports can also be accessed in the trial project information via the Trial Explorer.

The link to the Online Farm Trials is http://www.farmtrials.com.au/

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