



planning/paddock preparation • pre-planting • planting • plant growth and physiology • nutrition and fertiliser • weed control • insect control • nematode control • diseases • plant growth regulators and canopy management • harvest • storage • environmental issues • marketing • current research



Start here for answers to your immediate barley crop management issues

What variety should I grow?



What's the latest thinking on frost management in 2016?



How do I determine the optimum sowing rate?



What's the best approach for managing foliar diseases including rust?



What pre-emergent herbicide options do I have?



How do I implement harvest weed seed control?





Keys to successful barley production

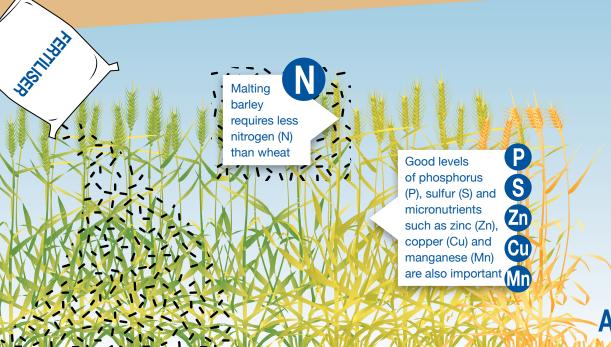




GOOD MOISTURE CONDITIONS

Aim for a plant population of 100–120 PLANTS/M² depending on variety and rainfall zone

Plant barley AS EARLY AS POSSIBLE in the recommended window



AS SOON AS POSSIBLE

Use soil testing and fertilise to achieve protein of

10-11% (DRY BASIS)

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Development

Corporation

Know more. Grow more.

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SECTION A

Introduction

A.1 Crop overview

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

Barley (Figure 1) 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–Middle East region.

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.



Figure 1: Barley has long been an important food crop. (Photo: Rachel Bowman)

Over the past 5 years, Australian barley farmers produced an average of 7.5 million tonnes (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. ¹

Australia produces high-quality 2-row spring-type barley, with annual production averaging \sim 7.0 Mt/year. It is a widely grown crop (second only to wheat) and occupies



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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



a large geographic area—almost 4 Mha, dispersed from Western Australia to southern Queensland.

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, $sh\bar{o}ch\bar{u}$ (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 $\sim 30-40\%$ of the national crop selected as malting.

Domestically, malting barley demand is \sim 1 Mt/year and Australian domestic feed use \sim 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.

In addition, Australia exports around 1.5 Mt of malting barley and ~2.5 Mt of feed barley. Major exporting states are Western Australia and South Australia, where domestic demand for malting and feed barley is considerably smaller than in the eastern states.

Australia makes up >30% of the world's malting-barley trade and $\sim20\%$ of the global feed-barley trade. On a production basis (as opposed to actual inter-country trade), Australia makes up $\sim5\%$ of the world's annual barley production. 2

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. 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 will generally 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.

The major determinant of barley profitability is yield. ³ To maximise yield, it is important to ensure that the crop has every chance to succeed.⁴

Paddock selection and nitrogen (N) management are often the keys to producing malting quality. ⁵ Use adequate N fertiliser but do not over-fertilise because this will encourage excessive vegetative growth and could result in lodging, and excess protein levels (above malting requirements) if applied late. Phosphorus, zinc and sulfur levels are also important. A starter fertiliser is recommended.

Growers should record paddock rotations or use soil-testing to ensure adequate nutrition. To grow a barley crop of 4 t/ha at 11.5% protein requires 144 kg N/ha, and adequate phosphorus.

Inspect barley crops regularly for insect infestations and foliar diseases and consult your agronomist about potential control methods. $^{\rm 6}$

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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

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



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 you have grown before. 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 v. 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 will give the greatest return requires consideration of factors including relative yield, disease resistance, the probability of achieving particular quality grades, and the relative End Point Royalty (EPR) charged on varieties.

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

Farmers now growing only feed varieties should consider including some malting varieties in their cropping. However, growers should 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 important to ascertain whether the variety chosen can be stored and marketed in your area. ⁸

A.2 Malting barley and malt

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 $\sim 10\%$ 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, whereby 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



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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

Agriculture Victoria. Growing barley. DEDJTR Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-barley



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, condiments and as a caramel substitute.

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. ⁹

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 (e.g. Urambie() and Yambla) 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 on the seed or in the crop to observe the withholding periods for grazing or cutting for hay or silage. ¹⁰

A.3 Southern Barley Agronomy project

Several key points emerged from this Grain Research and Development (GRDC)-funded project, which ran from 2008 to 2010.

In South Australia:

- Pre-emergent herbicide damage was more pronounced at shallow sowing depths, due to rain after application.
- Fleet() (long coleoptiles) is better sown deeper with recommended rates of preemergent herbicide.
- Hindmarsh(1 (short coleoptile) is better sown shallow (herbicide is less damaging than deep sowing).
- Oxford was the highest yielding variety in 2010.
- When N was managed correctly, there was no difference in the yield of a variety between early and late sowing. Timing was more important than rate for yield and quality.
- The late application of N at growth stage (GS) 30–37 was most profitable in malt varieties Buloke⁽¹⁾ and Commander⁽¹⁾.
- Crop sensors (NDVI measurements) can assist N management.
- Gairdner was the only variety not to suffer a yield penalty with multiple grazing events.
- Fleet() and Maritime() produced the most dry matter for early grazing.

In Victoria:

- Mid-May sowing gave the highest yields, but the yield penalty for late (June) sowing
 was not as severe as in drier years. April sowings suffered from locusts.
- Hindmarsh was the highest yielding variety; Commander yielded well and achieved the best gross margin because of the higher price for malt.
- Responses to N were similar in all varieties.
- Timing of N application was not important, so split or delayed applications (up to the 4-leaf growth stage) allowed seasonal risk to be managed.
- Leaf scald caused yield losses of 10–20% in susceptible varieties in the Wimmera but only 5–7% in the Mallee. Leaf scald was effectively managed with seed treatments and early fungicide application.



GRDC Ground Cover:
Avoid deep sowing for short-coleoptile barley

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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.





SECTION 1

Planning and paddock preparation



GRDC Update Papers: Barley agronomy in southern NSW

1.1 Agronomy tips at a glance

- Plant barley as early as possible in the recommended window.
- Plant into good moisture conditions.
- Aim for a plant population of 100–120 plants/m², depending on variety and rainfall
- Use good-quality, treated planting seed.
- Use soil testing and fertilise to achieve protein of 10-11% (dry basis).
- Malting barley requires less nitrogen (N) than wheat.
- Good levels of phosphorus (P), sulfur (S) and micronutrients such as zinc (Zn), copper (Cu) and manganese (Mn) are also important.
- Harvest as soon as possible. 1

Paddock selection 1.2

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

- Nitrogen status should be appropriate for expected yield level.
- Soil pH (CaCl₂) 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 presowing 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. Disease reaction for current varieties can be found at NVT South Australian Sowing Guide 2015 (p. 18) and NVT Victorian Winter Crop Summary 2015 (p. 29).

Know more. Grow more.

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DAF Qld (2011) Barley malting, feed varieties and sowing times. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/ malting,-feed-varieties-and-sowing-times

L Lenaghan, T Fay, M. Evans (2001) Paddock selection is critical for reliable malt barley production.



Paddock rotation and history

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

More information

Research paper: Break crops pay in the Victorian Mallee

Research paper: Effect of agronomic management on gross margins from crop sequences in the high rainfall zone of south western Victoria

Research paper: Increasing mycorrhizal colonisation does not improve growth and nutrition of wheat on Vertosols in southeastern Australia

Research paper: Rotation, sequence and phase. Research on crop and pasture systems

GRDC Fact Sheets: Choosing rotation crops. Short-term profits, longterm payback

GRDC Ground Cover: Crop sequencing supplement

GRDC: Integrated disease management for cereal and broadleaf crops in southern NSW and northern Victoria

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

GRDC Update Papers: Crop sequencing—what are the key issues to making profitable and sustainable decisions?

GRDC Update Papers: Drivers of profit and success—use of technology on the farm

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
- 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 and produces early grazing
- produces more dry matter than wheat, leaving very good stubble cover and valuable straw for livestock feeding
- a good choice for silage or hay—can regrow 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-test and record paddock rotations to determine adequate crop nutrition. A barley crop of 4 t/ha at 11.5% protein uses about 144 kg/ha of N and some P. 4

1.3.2 Disadvantages of cereals as a rotation crop

Growing cereals in continuous production is no longer a common practice because of the rising incidence of:

- difficult-to-control and herbicide-resistant weeds, particularly grass weeds
- disease build-up, e.g. crown rot, Rhizoctonia, CCN, RLN, 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

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

Leading growers and advisers advocate sustainable crop sequences as a valuable strategy for southern farming systems. However, many growers are sacrificing cereal

- 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
- DAF Qld (2014) Barley planting and disease guide. Department of Agriculture and Fisheries Queensland, https://www.daf.gld.gov.au/ data/assets/pdf file/0003/145587/Barley-Planting-Guide-2014.pdf
- 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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yield and protein by not adopting current research findings on the use of correct sequences. 6

information

GRDC Fact Sheets: Summer fallow spraying

GRDC Update Papers: Achieving good preemergent spray results

GRDC Update Papers: Impact of crop residues on summer fallow weeds

GRDC Update Papers: Summer weeds reduce moisture and nitrogen

GRDC: Summer fallow weed management



GRDC: Weed Webinars

GRDC: Integrated Weed Management Hub

1.4 Fallow weed control

Paddocks generally have multiple weed species present at one time, making weedcontrol decisions more difficult and often meaning a compromise after assessment of the prevalence of key weed species. Knowing your 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; however, for advice on individual paddocks you should contact your agronomist.

Benefits of fallow weed control are significant:

- · Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer before in a long fallow) is integral to cropping, particularly so as the climate moves towards summer-dominant rainfall.
- Modelling studies show that the highest return on investment in summer weed control is for lighter soils or in situations where soil water that would support continued weed growth is present. 7

1.4.1 **Double-knock strategies**

Double-knock refers to the sequential application of two different weed-control tactics applied in such a way that the second tactic controls any survivors of the first. Most commonly used for pre-sowing weed control, this method can also be applied in-crop. 8

Double-knock herbicide strategies are useful tools for managing difficult-to-control weeds but there is no 'one size fits all' treatment.

The interval between double-knock applications is a major management issue for growers and contractors. Shorter intervals can be consistently used for weeds where herbicides appear to be translocated rapidly (e.g. in awnless barnyard grass) or when growing conditions are very favourable. Longer intervals are needed for weeds where translocation appears slower (e.g. in fleabane, feathertop Rhodes grass and windmill grass).

Critical factors for successful double-knock approaches are for the first application to be on small weeds, and to ensure good coverage and adequate water volumes, particularly when using products containing paraquat. Double-knock strategies are not fail-proof and are rarely effective for salvage weed-control situations unless environmental conditions are exceptionally favourable.

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



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GRDC (2011) Short-term profits, long-term payback. Northern Region. Choosing Rotation Crops Fact Sheet, GRDC, March 2011, http://www.grdc.com.au/~/media/9219D55FFB4241DC9856D6B4C2D60569.pdf

GRDC (2012) Summer fallow—make summer weed control a priority. Western Region. Summer Fallow Management Fact Sheet GRDC, January 2012, http://www.grdc.com.au/~/ media/91deacef2dd843f6bbf9fab09bfe0d65.pdf

C Borger, V Stewart, A Storrie. Herbicides - knockdown herbicides for fallow and pre-sowing control. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/herbic herbicides?page=0%2C1



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. 9

Note that there are also in-crop herbicides that have plant-back periods. Some are mentioned in Table 1. Imidazolinones are widely used in IMI-tolerant crops and are an important consideration in planning.

Table 1: Half-life of common pre-emergent herbicides and residual persistence from broadacre trials and paddock experiences 10

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

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 (<i>Eragrostis</i> 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)	6.5–139	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
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

More information

Agriculture Victoria:

Avoiding crop damage from residual herbicides

Australian Pesticides and Veterinary Medicines Authority

NSW DPI: Using preemergent herbicides in conservation farming systems

NSW DPI: Weed control winter crops

1.5.1 How do herbicides break down?

Herbicides break down via either chemical or microbial degradation. Chemical degradation occurs spontaneously, the speed depending on the soil type (clay or sand, acid or alkaline), moisture and temperature. Microbial degradation depends on a population of suitable microbes living in the soil to consume the herbicide as a food source.





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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

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



Both processes are enhanced by heat and moisture. However, they are both impeded by herbicides binding to the soil, and this depends on the make-up of the soil (i.e. pH, clay or sand, and other compounds such as organic matter or iron).

For these reasons, degradation of each herbicide should be considered separately and growers need to understand the soil type for each paddock and climate when interpreting re-cropping periods on the product label.

1.5.2 How can I avoid damage from residual herbicides?

Select an appropriate herbicide for the weed population present. Make sure that you 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, and 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. You 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.

Group B. The sulfonylureas

Sulfonylureas persist longer in alkaline soils (pH >7), where they rely on microbial degradation. Residual life within the SU family varies widely, with chlorsulfuron persisting for \geq 2 years and not suitable for highly alkaline soils. Triasulfuron persists for 1–2 years and metsulfuron generally for <1 year.

Legumes and oilseeds are most vulnerable to SUs, particularly lentils and medics. However, barley can also be sensitive to some SUs. Check the label.

Group B. The triazolopyrimidines (sulfonamides)

Debate remains about the ideal conditions for degradation of these herbicides. However, research in the alkaline soils of the Victorian Wimmera and Mallee, and the Eyre Peninsula in South Australia, has shown that sulfonamides are less likely to persist than SUs in alkaline soils. Plant-back periods should be increased in shallow soils.

Group B. The imidazolinones (IMIs)

Imidazolinones are very different from SUs because the main driver of persistence is soil type, not soil pH. They tend to be more of a problem on acid soils, but carryover does occur on alkaline soils. Research has shown that in sandy soils, such as on the Eyre Peninsula, they can break down very rapidly (within 15 months in alkaline soils), but in the heavy clay soils in Victoria they can persist for several years. Breakdown is by soil microbes. Non-IMI-tolerant oilseeds are most at risk. Widespread use of IMI-tolerant canola and wheat in recent years has increased the incidence of residues.

Group C. The triazines

Usage of triazines has increased to counter Group A resistance in ryegrass and because of high rates used on triazine-tolerant canola. Atrazine persists longer in soil than simazine. Both generally persist longer in high pH soils, and cereals are particularly susceptible to damage. Recent research in the USA indicates that breakdown rates tend to increase when triazines are used regularly, because the number of microbes able to degrade the herbicide can increase. This may mean that breakdown can take an unexpectedly long time in soils that have not been exposed to triazines for some years.



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Group D. Trifluralin

Trifluralin tends not to leach through the soil but it can be moved into the seedbed during cultivation or ridging. Trifluralin binds strongly to stubble and organic matter and is more likely to be a problem in paddocks with stubble retention. Barley is more tolerant than wheat, oats and lentils. Use knife-points to throw soil away from seed and sow deep.

Group H. The isoxazoles

Persistence in acid soils (pH <7) has not been fully tested, but research suggests that isoxazole persistence is expected to be longer than the label recommendations for legume crops and pastures. Isoxazoles will also persist longer in clay soils and those with low organic matter. Cultivation is recommended prior to re-cropping.

Group I. The phenoxies

Clopyralid and aminopyralid can be more risky on heavy soils and in conservation cropping, where they can accumulate on stubble. Even low rates can cause crop damage up to 2 years after application. They cause twisting and cupping, particularly for crops suffering from moisture stress.

Use of 2,4-D for fallow weed control in late summer may cause a problem with autumn-sown crops. There have been recent changes to the 2,4-D label, and not all products can be used for fallow weed control; check the label. The label recommends not to sow sensitive crops, especially canola, until after a significant rainfall event. Oilseeds and legumes are very susceptible to injury from 2,4-D.

Group K. Pyroxasulfone

Pyroxasulfone relies on microbial degradation, which is favoured by in-season rainfall. Label plant-backs are important, particularly for oats, durum wheat and canola. Residues will lead to crop stunting. ¹¹

1.6 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.

1.7 Seedbed requirements

Barley seed needs good soil contact for germination. This was traditionally achieved by producing a fine seedbed by multiple cultivations. Good seed–soil contact can now be achieved by the use of press-wheels or rollers. Soil type and soil moisture influence the choice of covering device.

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 \leq 60% if seedbed conditions are unfavourable.

Seedbed preparation is also important to emergence. A cloddy seedbed can reduce emergence rates because the clods reduce seed–soil contact, stop some seedlings reaching the surface, and allow light to penetrate below the soil surface. The coleoptile

Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. DEDJTR Victoria, <a href="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



Research paper: Pasture plant-back periods following application of simazine to control *Vulpia* spp.

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



BASF: Clearfield
Production System

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



senses the light and stops growing, and a leaf is produced while still below the surface. Cloddy soils also dry out more quickly. 13

1.8 Soil moisture

1.8.1 APSIM-Barley

The APSIM-Barley module of APSIM (Agricultural Production System Simulator) simulates the growth and development of a barley crop in a daily time-step on an area basis (per m², not single plant). Barley growth and development in this module respond to weather (radiation, temperature), soil water and soil N. The barley module returns information on its soil water and N uptake to the soil water and N modules on a daily basis for reset of these systems. Information on crop cover is also provided to the water balance module for calculation of evaporation rates and run-off. Barley root residues are passed from barley to the surface residue and soil N modules, respectively, at harvest of the barley crop. ¹⁴

For more information, visit: APSIM-Barley.

1.8.2 Dryland

Soil water can be effectively monitored to assist managers in crop decision support. However, highly accurate estimates of plant-available water may not be possible given the inherent variability of soils and currently available sensor technologies. ¹⁵

Technologies to support decision-making

Several technologies will provide a level of information useful in decision support without excessive investment. Read about them at: Estimating plant available water capacity.

Devices for soil monitoring

In-situ devices that have relatively small zones of measurement and rely on good soil—sensor contact to measure soil water are at a disadvantage in shrink—swell soils where soil movement and cracking are typical. This is more important in dryland than irrigated systems because seasonal soil water levels vary from above field capacity through to wilting point or lower. Consequently, the potentially high levels of error associated with cracking and soil movement and high levels of inherent soil variability mean that increased device replication would be necessary to have confidence in results. However, this increases capital cost. Some devices (capacitance, time-domain reflectometer) also have an upper measurement limit over which they are unable to measure soil water accurately. This may be an issue on high clay soils where moisture content at drained upper limit is likely to be >50% volumetric, the common limit for these devices.

By comparison, the use of a portable electromagnetic induction (EMI) device to measure bulk electrical conductivity and calculate soil water has a number of advantages. EMI is quick, allowing for greater replication, measures the soil moisture of a large volume of soil (to 150 cm depth), is not affected by cracking or soil movement, and does not require installation of an access tube, thus making it available for use on multiple paddocks. On the other hand, it is unsuitable for use in saline soils and does not apportion soil water to particular layers within the soil profile. ¹⁶



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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

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

N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Papers, 5 March 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water

N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Papers, 5 March 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water



EM38

Despite an extensive range of monitoring instruments now available, measuring paddock soil moisture remains a considerable challenge. Among the suite of instruments currently available, one that is increasingly being used by researchers and agronomists is the EM38 (Geonics Ltd, Ontario, Canada). This EMI instrument is proving to have significant application potential for determining soil properties useful in precision agriculture and environmental monitoring. It is now commonly used to provide rapid and reliable information on properties such as soil salinity and sodicity, which can then be used to identify soil management zones.

It is also used in many agronomic and environmental applications to monitor soil water within the root-zone. It provides an efficient means to monitor crop water use and plant-available water (PAW) in the soil profile throughout the growing season so that informed management decisions can be made (e.g. the application, timing and conservation of irrigation water and fertiliser). EM38 datasets have also proved valuable to test and validate water balance models, which are used to extrapolate to other seasons, management scenarios and locations.

EM38 is an easy-to-use geophysical surveying instrument that provides a rapid measure of soil electrical conductivity. Soil calibrations or qualitative assessments can be used to convert this to estimates of soil water in the root-zone. ¹⁷

Calibration of monitoring devices

Electronic monitoring tools require calibration to convert the device output signal into information easily understood by the user (e.g. millivolts to volumetric soil water or PAW). This process requires the development of a relationship between sensor output and physically measured soil moisture content at moisture levels from dry to wet. The resulting calibration is then used to convert device output signal to gravimetric or volumetric water content.

Calculation of the availability of soil moisture for crop use (in mm of available water) requires further processing of the data and knowledge of a soil's PAW capacity (PAWC). A suitable characteristic may be identified from the APSoil database or SoilMapp, or electronic sensor output may be used to identify the soil's water-content operating range and reasonable assumptions made on values for drained upper limit and crop lower limit. An alternative is to use Soil Water Express, a tool that uses the soil's texture, salinity and bulk density to predict PAWC and to convert electronic sensor output to meaningful soil water information (mm available water).

Modelling of soil water

Simulation of the water balance should be considered as an alternative to field-based soil-water monitoring. Considering the error surrounding in-field measurement and issues regarding installation of sensing devices, there is a reasonable argument that the modelling of the water balance, when initialised with accurate PAWC and daily climate information, is likely to be as accurate as direct measurement. APSIM and Yield Prophet successfully predict soil water and they should be considered for both fallow and cropping situations. CliMate is a suitable choice for managing fallow water. 18

Testing for nitrate and available water by taking 0–60 cm cores prior to sowing is also common practice in the Southern Region.

Agronomist's view



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J Foley (2013) A 'how to' for getting soil water from your EM38 field measurements. GRDC Update Papers, 5 March 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-how-to-for-getting-soil-water-from-your-EM38-field-measurements

N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Papers, 5 March 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water



Subsoil constraints

Soils with 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.¹⁹

Effect of strategic tillage

Research shows that one-time tillage with a chisel or offset disc in long-term notill systems helped to control winter weeds and slightly improved grain yields and profitability while retaining many of the soil-quality benefits of no-till farming systems.

Tillage reduced soil moisture at most sites; however, this decrease in soil moisture did not adversely affect productivity. This could be due to good rainfall received between tillage and seeding and during the growing season. The occurrence of rain between tillage and sowing or immediately after sowing is necessary to replenish soil water lost from the seed-zone. This suggests the importance of timing of tillage and of considering the seasonal forecast. Future research will determine best timing for strategic tillage in no-till. ²⁰

1.8.3 Irrigation

Barley has not been a traditional irrigation crop because of its susceptibility to waterlogging on older irrigation layouts and the lack of suitable varieties for the cooler and wetter environment of the southern irrigation areas. However, barley has a number of good agronomic attributes for these regions compared with other cereals.

It has a shorter growing season so it requires less water to finish and can fit into a double-cropping program. Local and export demand is normally good for malting and feed-grade barley. There are few stripe rust issues in barley (some varieties are susceptible to barley grass stripe rust); it provides good weed suppression and generally has lower input costs. These attributes, combined with the features of recently developed varieties, have led to increasing interest in barley as an irrigated crop.

Management of the crop can be flexible. Variety choice, seeding rate and fertiliser rates are determined according to how the crop will be watered, that is:

- rainfed and residual irrigation water
- restricted watering (e.g. one spring irrigation)
- fully irrigated with the aim of achieving maximum yield and targeting malting quality ²¹

Barley has a high WUE rating. The plant can extract moisture from below 80 cm, and given a good starting moisture profile, high-yielding crops can be grown on limited irrigation. Yields of ≥7.3 t/ha have been recorded. Growers should target yields of 5–6 t/ha and protein content of 10.1% (dry) or 11.5% (wet basis) to maximise yield and quality. Requirements for water depend on winter rainfall and irrigation systems, but one of the crucial times to apply water for achieving malting quality is grainfill. Adequate moisture during tillering and early jointing is important for maximising potential yield. ²²

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¹⁹ 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

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

K O'Keeffe, N Fettell (2010) Barley varieties & sowing rates for irrigation. IREC Farmers' Newsletter No. 182, Autumn 2010, http://irec.org.au/farmer_f/pdf_182/Barley%20proves%20valuable%20for%20irrigation%20 rotations pdf

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



1.9 Yield and targets

1.9.1 Variety yield comparisons

See the <u>National Variety Trial</u> website to compare the performance of current barley varieties across the southern region.

1.9.2 Seasonal outlook

'The Break' newsletter is a good and highly regarded source of climate information for southern regions. It is produced by Agriculture Victoria regularly through season and reviews climate models and changes to key influences on southern rainfall. To view issues and to subscribe, visit: The Break, The Break, <a href="https://doi.org/10.108/j.chm.new

For tips on understanding weather and climate drivers including the Southern Oscillation Index, visit the <u>Climate Kelpie</u> 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: <u>Climate Kelpie MCV Climate Champion program</u>.

Australian <u>CliMate</u> is a suite of climate analysis tools delivered on the Web, iPhone, iPad and iPod Touch devices. CliMate allows you 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:

- 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 belowaverage rainfall or radiation?
- Based on the season's progress (and starting conditions from HowWet/N?), should I adjust inputs?

Season's Progress? asks for the weather variable to be explored (rainfall, average daily temperature, radiation, heat sum with base temperatures of 0, 5, 10, 15 and 20°C), a start month and duration. Text and graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation. ²³

The Bureau of Meteorology has moved from a statistics-based to a physics-based (dynamical) model for its seasonal climate outlooks. The new system has better overall skill, is reliable, allows for incremental improvements in skill over time, and provides a framework for new outlook services including multi-week/monthly outlooks and the forecasting of additional climate variables. ²⁴



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²³ Australian CliMate. Commonwealth of Australia, <u>www.australianclimate.net.au</u>

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



1.9.3 Fallow moisture

For a growing crop, there are two sources of water: that stored in the soil during the fallow, and that falling as rain while the crop is growing. As a grower, you have some control over the stored soil water; you can measure how much is present before you plant the crop. However, rainfall is out of your control. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry, but they cannot guarantee rain will fall when you need it. ²⁵

HowWet?—a climate analysis tool

The climate analysis tool *HowWet?* (from CliMate) uses records from a nearby weather station to estimate how much PAW has accumulated in the soil and the amount of organic N that has been converted to available nitrate during a fallow. It tracks soil moisture, evaporation, run-off and drainage on a daily time-step. Accumulation of available N in the soil is calculated based on surface soil moisture, temperature and soil organic carbon.

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.

Barley is grown in regions where stored soil water and nitrate at planting are important in crop-management decisions, and this tool can answer questions such as:

- How much longer should I fallow? If the soil profile is near full, perhaps the fallow can be shortened.
- Given the soil type and local rainfall to date, what is the relative soil moisture and nitrate-N accumulation over the fallow period compared with most years? (Relative changes are more reliable than absolute values.)
- Based on estimates of soil water and nitrate-N accumulation over the fallow, what adjustments are needed to the N supply?

Inputs:

- a selected soil type and weather station
- an estimate of soil cover and starting soil moisture

The stand-alone version of HowOften? uses rainfall data input by the user.

Outputs:

- a graph showing plant-available soil water for the current year and all other years and a table summarising the recent fallow water balance
- a graph showing nitrate accumulation for the current year and all other years

HowWet? uses a standard water-balance algorithm from Howleaky? and a simplified nitrate mineralisation. Further calibration is needed before accepting with confidence absolute value estimates. Soil descriptions are based on generic soil types with standard organic carbon and C/N ratios, and as such should be regarded as indicative only and best used as a measure of relative water accumulation and nitrate mineralisation.

For more information, visit: http://www.australianclimate.net.au/About/HowWetN.





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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

Australian CliMate. HowWet/N. Commonwealth of Australia, http://www.australianclimate.net.au/About/HowWetN



1.9.4 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:

- the soil's ability to capture and store water
- the crop's ability to access water stored in the soil and rainfall during the season
- the crop's ability to convert water into biomass
- the crop's 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) x (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.

A practical WUE equation for farmers to use developed by James Hunt of CSIRO is: $WUE = (yield \ x \ 1000)/available \ rainfall, \ where \ available \ rainfall = (25\% \ Nov.-Mar. \ rain) + (growing \ season \ rainfall) - 60 \ mm \ evaporation.$

Agronomist's view

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. ²⁷

Application of the French–Schultz model has been challenged in recent times. In the grainbelt of eastern Australia, rainfall shifts from winter-dominated in the south (South Australia, Victoria) to summer-dominated in the north (northern New South Wales and Queensland). The seasonality of rainfall, together with frost risk, drives the choice of cultivar and sowing date, resulting in a flowering time between October in the south and August in the north.

In eastern Australia, crops are therefore exposed to contrasting climatic conditions during the critical period for grain formation, i.e. a window of about 20 days before and 10 days after flowering, and this affects yield potential, and WUE.

Understanding how those climatic conditions affect crop processes and how they vary from north to south and from season to season can help growers and consultants to set more realistic target yields across sites, locations and seasons.

Researchers have analysed some of the consequences of the shift from winter to summer rainfall between southern and northern regions in terms of implications for management and breeding (see Figure 1). They note caution on the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more





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²⁷ GRDC (2009) Converting rainfall to grain. Northern Region. Water Use Efficiency Fact Sheet, GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Water%20Use%20Efficiency%20.North%20version%20
231009.pdf



integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single-crop and whole farming-system level (i.e. \$/ha.mm). ²⁸

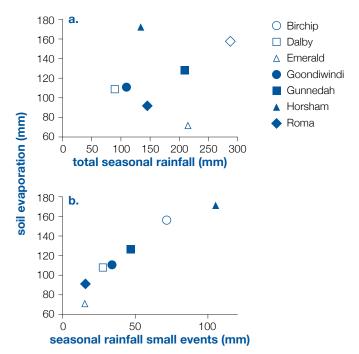


Figure 2: Simulated soil evaporation is (a) unrelated to seasonal rainfall and (b) closely related to rainfall in small events (i.e. ≤5 mm). Rainfall has three key features: amount, seasonality, and event size. The seasonality and size of events can be significant. The most widespread source of inefficiency in rainfall use, i.e. soil evaporation, is favoured by frequent and often small rainfall events. In southern locations, water supply is dominated by in-season rainfall, with characteristically small events and high evaporative losses.

More information

information

GRDC: Water use

benchmarks and

management

efficiency of grain crops in Australia: principles,

Agriculture Victoria: How to calculate fertiliser rates and costs

1.9.5 Nitrogen-use efficiency

Soil type, rainfall intensity and the timing of fertiliser application largely determine N losses from dryland cropping soils. Knowing the nutrient demand of crops is essential in determining nutrient requirements. Soil testing and nutrient audits assist in matching nutrient supply to crop demand.

1.9.6 Other factors

A mounting body of research shows that integrated weed management (IWM) approaches incorporating strategic crop sequences and rotations, herbicides and other tactics provide effective weed control within holistic production systems.

Similarly, it has long been recognised that introduction of legumes and ley phases into cropping sequences is an important means by which long-term improvements in soil fertility can be achieved. Recent GRDC-funded research has quantified the benefits in central Queensland. ²⁹

1.10 Disease status of paddock

Diseases remain a major threat to barley production in Australia but are generally well controlled at present. The average annual loss from barley diseases is estimated at AU\$252 million, or \$66.49/ha. This compares with a potential average loss nationally



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D Rodriguez, V Sadras (2008) Farming systems design and water use efficiency. Challenging the French & Schultz WUE model. GRDC Update Papers, 13 June 2008, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/06/Farming-systems-design-and-water-use-efficiency-WUE-Challenging-the-French-Schultz-Wue-model

⁹ R Sequeira (2010) Grower Solutions for Central Queensland. GRDC Research & Development, http://www.grdc.com.au/Research-and-Development/DAQ00170



of \$192 million from a single disease, spot form of net blotch, which is reduced to \$43 million by current controls. Major diseases in the Southern Region are CCN, spot form of net blotch, RLN, *Rhizoctonia* bare patch, take-all and crown rot. ³⁰

1.10.1 Soil testing for disease

<u>PreDicta B</u> (B = broadacre) 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 and P. thornei)
- crown rot (caused by Fusarium pseudograminearum)
- stem nematode (Ditylenchus dipsaci)

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 your local plant pathology laboratory.

For more information, visit: http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b.

1.10.2 Cropping history effects

Continuous cereal cropping increases the risk of diseases, including crown rot. This fungal disease is hosted by all winter cereals and many grassy weeds and the fungus can survive for many years in infected plant residues. Infection can occur when plants come in close contact with those residues. High cereal intensity and inclusion of durum wheat in cropping programs are factors that increase crown rot levels. 31

1.11 Nematode status of paddock—testing of soil

Paddocks should be tested for plant parasitic nematodes so that optimal management strategies can be implemented. Testing your farm will tell you:

- · whether nematodes are present and at what density
- · 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.

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 these nematodes is valuable information because it may be possible to take steps to avoid future contamination of that field. ³²

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³⁰ GM Murray, JP Brennan (2009) The current and potential costs from diseases of barley in Australia. GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Disease_Loss_Barley_Report_240809.pdf

³¹ GRDC (21014) Managing crown rot. Hot-Topics. Media Centre, GRDC, http://www.grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

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



Testing of soil samples taken before a crop is sown or while the crop is in the ground provides valuable information.

For more information, visit: http://pir.sa.gov.au/research/services/molecular_diagnostics/ predicta b.

1.12 Insect status of paddock

1.12.1 Insect sampling of soil

Soil-dwelling insect pests can seriously reduce plant establishment and populations, and subsequent yield potential.

Soil insects include:

- cockroaches
- crickets
- earwigs
- black scarab beetles
- cutworms
- false wireworm
- true wireworm

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.

Soil sampling by spade

- 1. Take a number of spade samples from random locations across the field.
- Check that all spade samples are deep enough to take in the moist soil layer (this is essential).
- 3. Hand-sort samples to determine type and number of soil insects.
- Spade sampling is laborious, time-consuming and difficult in heavy clay or wet soils.

Germinating seed bait technique

Immediately following planting rain:

- 1. Soak insecticide-free crop seed in water for at least 2 hours to initiate germination.
- 2. Bury a dessertspoon of the seed under 1 cm of soil at each corner of a 5 by 5 m square at five widely spaced sites per 100 ha.
- 3. Mark the position of the seed baits because high populations of soil insects can destroy the baits.





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One day after seedling emergence, dig up the plants and count the insects.

Trials have shown that there is no difference in the type of seed used when it comes to attracting soil-dwelling insects. However, use of the type of seed to be sown as a crop is likely to indicate the species of pests that could damage that crop.

The major disadvantage of the germinating grain-bait method is the delay between the seed placement and assessment.

Recognising soil insects

For more information, see *GrowNotes Barley South 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.

For current chemical control options see Pest Genie or APVMA. 33

More information

GRDC Hot Topics: Snail control before seeding

GRDC Fact Sheets: Snail bait application

VNTFA: Slugs

information

GRDC Ground Cover: Mouse management a numbers game

GRDC Update Papers: Surveillance and forecasts for mouse outbreaks in Australian cropping systems

GRDC Fact Sheets: Mouse control-Western Region

1.13 Snails

With the increased prevalence of snails and slugs in the southern cropping region in recent years, the GRDC has invested in a number of research and development programs mapping different species and looking at a range of control measures.

Have you noticed snails in grain at harvest? Are snails easily seen in some paddocks? If you answered yes to either of these questions, consider control measures in the lead up to sowing rather than after crops have germinated.

Use a 32 cm by 32 cm square quadrat and count all of the live snails in it. Multiplying by 10 will give an estimate of snails per m². Live snails are those that are moist when squashed. Taking many sampling points within paddocks known to have snails will give a good indication of their numbers and of where they are mostly found. 34

1.14 Mouse management

During years of high mouse activity, young winter crops can be severely damaged. Growers need to monitor crops closely and determine whether zinc phosphide baiting should be carried out to reduce damage to summer crops and protect newly sown winter crops. Growers are reminded that there is a 2-week withholding period for zinc phosphide baits prior to harvest. Talk to your neighbours and coordinate a baiting program to reduce reinvasion. 35



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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/integratedpest-management/help-pages/recognising-and-monitoring-soil-insects

GRDC (2014) snail control before seeding. Hot Topics. Media Centre, GRDC, http://grdc.com.au/Media-Centre/Hot-Topics/Snail-control-before-seeding

J Farrell, PR Brown (2014) Mouse plague prediction models: relevant forecasts for growers in Queensland. GRDC Update Papers, 5 March 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Mouse-plague-prediction-models-relevant-forecasts-for-growers-in-Queensland



SECTION 2

Pre-planting



More information

GRDC Update Papers:
Using crop competition
for weed control in
barley and wheat

GRDC Update Papers:
New and potential
malting barley variety
update and agronomic
developments

GRDC Update Papers: Barley agronomy results 2014

GRDC: Crop Variety
Guides

2.1 Varietal performance and ratings yield

2.1.1 Selecting barley varieties

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 for which selection of resistant varieties can improve performance and reliability.

The variety chosen should be:

- · appropriate for the environment
- · suitable to the sowing time
- able to be segregated in the case of malting varieties ¹

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 resistances with those of the currently grown varieties.

Grains industry productivity is dependent upon 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 seek to 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. ²

Individual trial results from NVT provide only a snapshot in time and may lead to unsuitable varietal choice. Combining data across trials and years enhances the chance of selecting the appropriate varieties, and the current long-term analysis is based on geographic region. A new method of analysis forms environment groups from similar trials rather than geographic regions and provides the most accurate prediction of relative yield performance of varieties for an environment. ³

2.1.3 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

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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

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

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



are arrived at by assessing the maturity of varieties in different environments and with different sowing times.

After grain-filling, 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%).

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.

A rapid decline in grain moisture occurs after physiological maturity. 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.

Barley is physiologically mature at 30–50% moisture, which is well before it is ripe enough to harvest mechanically. $^{\rm 4}$

2.1.4 Malting and other quality traits

Malting varieties

Malting barley varieties in Australia are accredited by Barley Australia. They undergo rigorous testing to ensure that they meet malting standards both for domestic and international markets. The <u>Barley Australia</u> website has a list of currently accredited varieties. Delivery of malting varieties will depend on segregations in your region and must meet the Grain Trade Australia (GTA) quality standards/specifications for malting barley.

For more information, see: Barley Australia: Preferred varieties list

WARNING: Malting barley may only be treated with phosphine, dichlorvos, fenitrothion or methoprene for insect control. Check with the end-user prior to treatment to ensure that a particular pesticide is acceptable. ⁵

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.
- 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.





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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

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

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



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 malting barley variety purity test that will ensure our reputation is maintained.





GRDC Driving
Agronomy Podcasts:
New barley test.

The commercial test, developed with funding from GRDC, helps growers to ensure that they are growing malting barley varieties most sought after by maltsters. Malting barley varieties are increasingly more difficult to differentiate. GrainGrowers collaborated with the GRDC and DArT to deliver the DNA test, which is capable of identifying even low levels of contamination. The test can determine how pure your variety is and which other varieties may be present in a sample. For more information, visit: GrainGrowers-Products and Services-Barley testing.

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 retention, before they can be accepted into Food Barley segregations. This classification was developed to accommodate Hindmarsh, a variety developed to supply maltsters but which failed to gain malting accreditation.

Feed varieties

Feed accredited varieties include any 2-row varieties with white aleurone layer. 7,8

2.1.5 Other varietal traits

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.

Greg Platz, of Agri-Science Queensland, co-ordinates this project, and pathologists and technicians across Australia gather data on 15 diseases of barley. For some of these diseases, such as leaf rust and net form of net blotch, at least six different pathotypes are used, providing a comprehensive evaluation of resistance.

The protocols for seed distribution, data collection and reporting mirror those used in the wheat disease-screening project, although on a smaller scale. There were 19 NVT

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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

GTA (2013) Barley standards. 2013/2014 season. Grain trade Australia, http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/2013 2014/Section%2002%20-%20Barley%20Standards%20 201314%20Final.pdf





lines and 48 released barley varieties (commonly referred to as the AUSBAR set) in the 2012 series.

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. ⁹

Frost ratings

Grain growers and their advisors 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 <u>GrowNotes Barley South Section 14</u>. <u>Environmental issues</u>.



2.1.6 Varieties

Admiral[®]: New malting barley developed by Joe White Maltings and the University of Adelaide. It is a semi-dwarf variety with stiff straw and maturity slightly later than Gairdner, hence is suited to environments with high yield potential. Offers good resistance to net form net blotch, powdery mildew, leaf rust, and cereal cyst nematode (CCN), but is susceptible to spot form of net blotch. Can be grown under production contracts for supply to AWB and Joe White Maltings.

BARLEYmax: Specialty barley for the human food consumption market. Early–mid-season maturity. Dark-coloured, semi-hull-less seed with a shrunken endosperm. Susceptible to powdery mildew and spot form of net blotch. Marketed by Austgrains Pty Ltd.

Bass®: Malting. Baudin® replacement with excellent grain plumpness and high test weights, suited to districts of medium to higher rainfall. Similar maturity to Baudin®. Moderately short variety with good straw strength and head retention. Improved disease resistance compared with Baudin®. Restricted segregations likely. (InterGrain)

Baudin@: Malting. Excellent malting quality. A Gairdner replacement with earlier maturity (rated mid-season) and lower screenings. Adapted to medium-rainfall areas. Short with excellent straw strength and head retention. Susceptible to spot form of net blotch, very susceptible to powdery mildew and leaf rust. Released by the Department of Agriculture and Food Western Australia (DAFWA) in 2002. (Seednet)



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G Hollaway, G Platz (2012) Coordinated disease management. National Variety Trials supplement. GRDC Ground Cover Issue 101, <a href="http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/%7E/link.aspx?id=5D5E733823CC402E9F0950A9EB1FF9F9&z=z]





Binalong: Feed. Good straw strength and high yield potential in the north. Medium–slow maturity. Moderate grain size. Resistant to powdery mildew. Very susceptible to net form of net blotch and susceptible to spot form of net blotch, leaf scald and leaf rust. Bred by NSW Department of Primary Industries (DPI). (Heritage Seeds)

Buloke⁽¹⁾: Malting. Excellent malting quality for export market. Tall, early-mid-season variety, with a flowering time similar to Schooner. Good levels of resistance to net form of net blotch and powdery mildew, susceptible to CCN, moderately susceptible to leaf scald and susceptible-very susceptible to leaf rust. Grain size bigger than Gairdner but smaller than that of the benchmark variety, Schooner. Exhibits sprouting tolerance similar to Gairdner and better head retention than Schooner. May lodge under conditions favouring high yield. Bred by Department of Primary Industries Victoria (DPI Vic.). (Seednet)

Capstan®: Feed. Very short variety, resistant to CCN, with outstanding straw strength and head retention. Best suited to high-input farming systems targeting very high yield. Also offers advantages in stubble management. Modest early vigour and potential for low test weights under drought stress should preclude it from drier districts. Bred by the University of Adelaide. (Viterra)

Charger® (CA412402): New malting barley developed by Carlsberg and Heineken Breweries in collaboration with the University of Adelaide. Mid-maturing with good straw strength and resistance to leaf rust and powdery mildew but very susceptible to net form of net blotch and leaf scald. Has shown consistently high grain yield particularly in favourable environments. Contract production is exclusively managed by Australian Grain Growers Cooperative.

Commander (b): Malting. Malting quality variety with maturity between Schooner and Gairdner. Plump grain size compared with other malting varieties. High yield potential and lower grain protein than Schooner and Gairdner when grown under the same conditions. Resistant to CCN but susceptible to scald. May lodge under early-sown conditions. Developed by the University of Adelaide. (Viterra)

Compass(*) (WI4593): Developed by the University of Adelaide as an early–mid-season maturing, potential malting-quality variety. Expected to complete Barley Australia malt accreditation 2018. Closely related to Commander but significantly higher yielding based on 2012 and 2013 NVT data in South Australia and 2009–15 data in the Mallee, Victoria. Similar growth habit to Commander but earlier flowering, with superior straw strength, lodging resistance and net form of net blotch resistance. Has previously shown good resistance to leaf rust but has shown susceptibility to a strain with virulence on the *Rph3* gene. Has shown good physical grain quality with high retention and low screenings and moderate test weight. Seed available from Seednet.

Fairview: Malting. A mid-late-season variety available only under contract to Malteurop. Better straw strength and grain size than Gairdner, it has performed particularly well under irrigation. Has an export malt quality profile.

Fathom®: Feed. Fathom is a feed-quality variety developed using wild barley to improve stress tolerance and water-use efficiency. Has a long coleoptile, good early vigour and with early maturity similar to Hindmarsh®, is best suited to lower and medium-rainfall environments. Moderately tall variety but shows good straw strength and excellent grain plumpness with screenings levels lower than both Fleet® and Hindmarsh®. Developed by the University of Adelaide. (Viterra)

Finniss(1): A hull-less barley released in 2009. Semi-dwarf type with a mid-maturity similar to Schooner. Good straw strength and head retention, resistance to CCN, leaf rust and scald. Very susceptible to powdery mildew. The agronomic improvements of Finniss(1) over current hull-less varieties is expected to improve the economic viability of hull-less barley production significantly for use in intensive livestock and niche humanfood applications. (Viterra)

Fitzroy®: Malting. Medium-maturing to medium-late-maturing variety with improved disease resistance over Gairdner and acceptable grain size. Semi-dwarf plant with good





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seedling vigour, medium height and good straw strength. Best suited to northern New South Wales and Queensland barley-growing areas. Best results will be achieved in more favourable environments. Can exhibit low test weights under stressed conditions. (Seednet)

Flagship(I): Malting. Good malting qualities, particularly for South East Asian markets. Tall, early-mid-season maturity variety, similar in plant type to Schooner. Excellent early vigour and weed competitiveness, but modest straw strength with lodging resistance similar to Schooner. Resistance to CCN and *Pratylenchus neglectus*. Prone to preharvest weather damage. (Heritage Seeds)

Fleet(I): Feed. Tall, early-mid-season variety resistant to CCN. Exhibits a good disease-resistance profile and good physical grain quality. May lodge under high-yielding conditions. Developed by the University of Adelaide. (Viterra and the Australian Field Crops Association)

Flinders: Malting. A moderately late-maturing variety. Moderately short with stiff, strong straw and good head retention. It has high levels of grain plumpness and good test weights. Susceptible to leaf scald, spot form of net blotch and net form of net blotch, resistant—moderately resistant to powdery mildew and moderately susceptible to leaf rust. Although not as high-yielding as the earlier maturing LaTrobe or Compass of, Flinders offers a replacement for Baudin and Gairdner with a longer season option and will be available pending final malt accreditation. Developed by InterGrain. Released 2012. Seed available from Syngenta. EPR \$3.80.

Gairdner: Malting. Adapted to areas of medium to higher rainfall (>400 mm). Mid–late-season maturity and strong straw. Best sown early. Gairdner has a thin grain, producing significantly greater screenings losses than Schooner and is ~1% lower in grain protein. Resistant to *Barley yellow dwarf virus* (BYDV). Susceptible–very susceptible to the spot form of net blotch and susceptible to CCN. Developed by DAFWA. (Heritage Seeds)

Grange: Malting. A medium–late, high-yielding, broadly adapted barley with excellent malt extract and good diastatic power. Targeted for the domestic malting industry as a potential Gairdner replacement. Performs better than Oxford under late planting. On average 10 cm taller than Baudin and 3–4 cm taller than Gairdner, but with better, larger kernel size (2–4 g/1000 grains) and lower screenings. Resistant to powdery mildew and resistant–moderately resistant to leaf rust. Variable reaction to net form of net blotch, depending on pathotype present, and susceptible to spot form of net blotch. Susceptible–moderately susceptible to barley scald, depending on region. Licensed to Heritage Seeds by Nickerson-Limagrain, UK.

Granger A mid-late-maturing variety with strong straw, and good kernel plumpness and low screenings. Moderately susceptible-susceptible to leaf scald, moderately susceptible to spot form of net blotch, moderately resistant-moderately susceptible to net form of net blotch, resistant to powdery mildew and moderately resistant to leaf rust. Accredited as malting barley in 2013, export markets are being established and growers are advised to consult with their grain marketer about segregation and pricing. Released 2013. Tested as SMBA09-3353. Licenced by Limagrain and seed available from Heritage Seeds. EPR \$2.95.

Grimmett⁽¹⁾: Malting. Reliable malting variety for the northern region. Suitable for midseason and late plantings, particularly in western areas. Very good grain size. Consider seed treatment for net blotch and powdery mildew.

Grout D: Feed. Quick-maturing variety with good grain size, suited to northern New South Wales and Queensland. Matures up to 2 weeks earlier than Grimmett D from a mid-May to mid-June planting. Vigorous seedling with a high tillering ability and erect growth habit. Medium height with moderate standability, better than Grimmett D and similar to Mackay D. Good resistance to powdery mildew. Leaf rust needs to be managed, rated as very susceptible. (Seednet)

Hindmarsh D: Food. Erect, semi-dwarf variety. Flowers earlier than Schooner and is widely adapted to low- and medium-rainfall areas. Excellent yield potential, grain



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plumpness close to Schooner, and high test weight. Resistant to CCN and moderately resistant–moderately susceptible to net form of net blotch. Very susceptible to spot form of net blotch and susceptible–moderately susceptible to leaf rust. Variable response to leaf scald, depending on the pathotype present. Short coleoptile, so deep sowing should be avoided. Has been given a new classification (food) and may be segregated for human food and possibly used for shōchū (Japanese distilled spirit) and for malt production in some markets. Developed by DPI Vic. (Seednet)

Keel: Early-flowering, high-yielding, feed-quality variety released in 1999. Now generally outclassed by Hindmarsh and Fleet in South Australia. Very susceptible to leaf rust and, in recent years, susceptible to net form net blotch, further detracting from this once very popular variety.

LaTrobe() (IGB1101): Malting. Early-maturing semi-dwarf variety with growth habit and plant architecture very similar to Hindmarsh(). Agronomic performance has also been similar to Hindmarsh(). Resistant to CCN and net form of net blotch but susceptible to spot form of net blotch like Hindmarsh(). Seed available from Intergrain Pty Ltd.

Mackayd: Feed. Mid-season variety with good resistance to lodging. Large grain size. Adequate resistance to leaf rust and powdery mildew. Variable response to net form of net blotch, depending on the pathotype present. Susceptible–very susceptible to spot form of net blotch. Partially resistant to common root rot. Bred by Department of Agriculture and Fisheries Queensland. (Heritage Seeds)

Maritime(b: Tall, early-maturing feed variety with CCN resistance released by the University of Adelaide in 2004. Developed specifically for manganese-deficient soils where it exhibits good adaptation. Moderate to high yield potential on other soil types, and did offer a good disease resistance profile but now very susceptible to net form net blotch. Excellent physical grain quality and early vigour, and a good option for lower rainfall environments where tall straw and high test weights are sought but in areas of low risk of net form of net blotch. Seed available through Seednet.

Navigator(b: Malting. A semi-dwarf variety suited to the domestic malt market. Similar in maturity to Gairdner but offers shorter straw, better physical grain quality and higher yield. Recommended for medium-high-rainfall areas. Good resistance to CCN, spot form of net blotch and net form of net blotch, and strong resistance to scald. Good resistance to lodging. Very susceptible to leaf rust. Bred by the University of Adelaide. (Viterra)

Oxford: Feed. A medium–late-maturing variety similar to Gairdner. High yield potential, with wide adaptation. Excellent head retention with above-average test weight and excellent grain colour. Good straw strength and resistance to lodging. Resistant to powdery mildew and moderately resistant to leaf rust. Moderately susceptible to net form of net blotch and susceptible to spot form of net blotch. (Heritage Seeds)

Schooner: Malting. Formerly a major central and southern malting variety favoured for its reliability in maintaining grain size, although lower yielding than later releases. Can be prone to pre-harvest head loss. Susceptible to powdery mildew and susceptible–very susceptible to leaf rust and showing increasing susceptibility to leaf scald.

Scope CL(): Malting. Imidazolinone-tolerant barley with tolerance to label rates of Intervix® herbicide. Check current herbicide registrations for registered product rates. Tall, early–mid-season variety with a flowering time similar to Buloke(). Resistant to powdery mildew and moderately resistant to net form of net blotch but susceptible to CCN. Developed by Agriculture Victoria and Seednet.

Shepherd(1): Feed. Slightly later maturing than Grout(1) but similar in growth habit with erect vigorous early growth. Suited to medium-rainfall areas of northern New South Wales and Queensland. Moderately resistant to leaf rust and with variable response to powdery mildew and net form of net blotch, depending on the pathotype present. Susceptible–very susceptible to spot form of net blotch. (Seednet)

SouthernStar: New malting barley developed by Sapporo Breweries and the University of Adelaide. Based on Flagship: and incorporates a patented novel gene

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for improved beer quality. Has almost identical agronomic characteristics to Flagship the with good early vigour, CCN resistance and a strong foliar disease resistance profile. Has sensitivity to sprouting so timely harvest must be a priority. Can be grown under production contracts for supply to Barrett Burston Maltings and Joe White Maltings.

SY Rattlerd: High-yielding, mid-maturity, potential malting barley with medium height and stiff straw. Good resistance to scald, powdery mildew and barley leaf rust; useful resistance to net form of net blotch. Coupled with excellent grain quality, SY Rattler has all the necessary attributes for the domestic brewing markets. Currently progressing through Barley Australia Malt Accreditation with a target accreditation date of 2017. Bred by Syngenta and seed available through GrainSearch.

Tilga: Feed variety suited to western areas. Tall with moderate straw strength in highyielding situations. Good grain size. Tilga has some light blue aleurone (skin) grain. Moderately resistant to net blotch but susceptible to powdery mildew. Susceptible to loose smut-use a seed dressing.

Tullad: Feed. Main-season variety. Tolerant of acid soil. Similar yields to Tantangara on non-acid soils. Moderate resistance to leaf scald. Bred by NSW DPI. (Waratah Seeds)

Urambie(1): Feed. Best suited to grain and grazing situations. Two-row barley, adapted to early sowing, having early maturity combined with a cold requirement for initiation of heading. Sowing window is early May-mid-June, earlier if grazed. Consistent yields across seasons but low grain quality. Resistant to leaf scald and net form of net blotch. (Waratah Seeds)

Vlamingh : Malting. Mid-season maturity between Schooner and Gairdner. Erect early growth and moderately tall. Grain plumpness is better than Gairdner. Best suited to high- and medium-rainfall zones. Good resistance to net form of net blotch. Confirm marketing arrangement for Vlamingh before planting. Released by the DAFWA. (Viterra)

Westminster D: Malting. A medium-late-maturity variety similar to Gairdner. Has exceptionally high yield potential and performs well under high-rainfall or irrigated conditions. Medium-tall variety with good straw strength and improved head retention compared to Gairdner. Good all-round disease resistance. Introduced malting barley from Nickerson International Research, licensed to GrainSearch in Australia.

Wimmera@: Malting. Mid-late-maturing variety with similar plant architecture to Gairdner. However, it has significantly higher yield potential and better physical grain quality. Wimmera showed resistance to leaf rust until a new strain to which it is susceptible emerged in 2011. (Viterra) 10

New releases from InterGrain are Rosalind (feed) and IGB1334T (imidazolinonetolerant, undergoing malt accreditation).

2.2 Planting seed quality

2.2.1 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 grain-filling 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 by Neil Fettell at Condobolin in 2008 showed that whereas small seed (25.64 g/1000 seeds) had emergence equal to 90% of that of large seeds (41.31 g/1000 seeds) when sown at 44 mm depth, emergence dropped to 67% when sown at 87 mm, and 53% when sown deep (at 112 mm).



National Variety Trial <u>Results</u>

Barley Australia: Varieties handbook

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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





GRDC Media Centre: Select the best when saving seed for next years crops Seed size is usually measured by weighing 1000 grains. This is known as the 1000-grain weight. The 1000-grain weight varies among varieties and from season to season. Sowing rate needs to vary according to the 1000-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. ¹¹

2.2.2 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)
- activation
- visible germination ¹²

Seed vigour includes the properties of the seed that determine the level of activity and performance of the seed or seed lot during germination and seedling emergence. In any seed lot, losses of seed vigour are related to a 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, i.e. complete loss of germination.

However, seeds lose vigour before they lose the ability to germinate. That is why seed lots that have similar high germination values can differ in their physiological age (the extent of deterioration) and so differ in seed vigour and therefore the ability to perform. ¹³

When purchasing seed, request a copy of the germination and vigour analysis certificate from your supplier. For seed stored on-farm, you can send 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 in soil at harvest and during storage:

- 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 and lay out the seeds. Moisten and place on a window-sill. Keep moist and count as per the method outlined below.
- 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 and pushing in with a pencil marked to the required depth. Cover with a little more sand or soil and water gently.

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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

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

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



- Keep soil moist but not wet; overwatering will result in fungal growth and possible rotting.
- After 7–10 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. ¹⁴

For more information on factors affecting germination, see <u>GrowNotes Barley South Section 4. Plant growth and physiology</u>.

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.

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

2.2.3 Seed storage

Barley is more susceptible to insect damage 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, 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 1).

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 \sim 12% moisture content. ¹⁵

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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

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



Table 1: An indication of the interaction between moisture and temperature

Storage temperature	Potential storage period
10°-20°C	Very long, 12-18 months
20°-30°C	Moderate, 6 months
>30°C	Short, 3 months
10°-20°C	Long, 12 months
20°-30°C	Moderate, 6 months
>30°C	Short, 3 months
10°-20°C	Moderate, 6 months
20°-30°C	Short, 3 months
>30°C	Very short, <3months
10°-20°C	Short, 3 months
20°-30°C	Very short, <3 months
>30°C	Perhaps, 1 month
	10°-20°C 20°-30°C >30°C 10°-20°C 20°-30°C >30°C 10°-20°C 20°-30°C >30°C 10°-20°C 20°-30°C

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. Four issues need to be considered: temperature, moisture, aeration and pests. The following are required:

- 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. 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.

2.2.4 Safe rates of fertiliser sown with the seed

Crop species differ in tolerance to N fertiliser when applied with the seed at sowing. 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.

Generally, the range of tolerance between crop species indicated in Table 2 does not appear to be large enough to recommend an increase in the rates from those already suggested in fertiliser handbooks and similar publications. However, the data do indicate the crop where extra caution may be required when ammonium fertilisers are applied near the seed.

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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



Table 2: Ranking of crop species establishment in their response (1, most tolerant; 6, least tolerant) to ammonia/ammonium applied in close proximity to the seed

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

With recent advances in understanding of the interaction of fertiliser and seed establishment, and the improved technology of sowing implements, the fertiliser application rate and its interaction with the soil environment remain the prime determinant of crop establishment in most years.

For individual sites and in individual years, modest modifications to application rates according to crop species may be advised given the information now available. The safest application method for high rates of 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). For fertilisers with lower ammonium content (e.g. mono-ammonium phosphate (MAP)), close adherence to the safe rate limits set for the crop species and the soil type is advised. 17

High rates of N fertiliser applied at planting in contact with, or close to, the seed will severely damage seedling emergence. If high rates of N are required, then it should be applied pre-planting or applied at planting but not in contact with the seed (i.e. banded between and below sowing rows). Table 3 indicates the maximum rates of fertilisers containing N that may be applied with the seed at planting, using conventional planting equipment. Rates should be reduced by 50% for very sandy soil and may be increased by 30% for heavy-textured soils or if soil moisture conditions at planting are excellent. Rates should be reduced by 50% when planting equipment with narrow disc or tine openers are used, because the fertiliser concentration is increased around the seed. 18

Table 3: Safe rates (kg/ha) of application of some nitrogen fertilisers with seed at planting

Row spacing (cm)	N	Urea	DAP	MAP STARTERFOS®
18	25	54	130	200
25	18	39	90	138
50	9	20	45	69
75	6	13	30	46

DAP, Di-ammonium phosphate; MAP, mono ammonium phosphate

Contact your agronomist or fertiliser supplier for details on other blends.



GRDC Update Papers: Pushing the production barriers

GRDC Update Papers: Local research **highlights**

GRDC Update Papers: Key outcomes arising from the crop sequence project

GCTV15: Dual purpose wheat spin



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



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SECTION 3

Planting



GRDC Update Papers: From soil throw to bentleg tine seeding research

GRDC Update Papers: Impact of elevated CO2 on aluminium tolerance of wheat in acid soils

GRDC Update Papers: Lifting productivity in retained stubble systems

GRDC Update Papers: Strategies and tactics to extend whole farm water use efficiency; sow on time or early

GRDC Update Papers:
Success with no-till into
pasture ground

GRDC Update Papers: Sowing dates—getting the best from our varieties and optimising whole farm wheat yield

GRDC Update Papers: Adding value through pasture and fodder break crops

GRDC Update Papers: Good stubble bad stubble — more profit less profit

GRDC Update Papers:
Pre-emergent herbicides
and seeding system
interactions

GRDC Update Papers: Nitrogen management in waterlogged crops

GRDC Videos: Lessons from 2014's early sown wheat in southern NSW Barley is very versatile with respect to 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 variety and region depending on frosts and seasonal effects.

Early planting 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.

The major determinant of barley profitability is yield. ¹To maximise yield, it is important to provide conditions for success. ² Paddock selection and nitrogen (N) management can be the keys to producing malting quality.³

3.1 Seed treatments

Seed treatments are applied to control diseases such as smuts, bunts and foliar diseases and to control insects. When applying seed treatments, always read the chemical label and calibrate the applicator. Treat seed with appropriate fungicidal dressing; smuts and net form of net blotch may be seed-borne.

It is critical that seed treatments are applied evenly and at the right rate. 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.

Some risks are 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 for varieties with shorter coleoptiles.

Seed dressings with systemic insecticides such as imidacloprid have been shown to have a net benefit for aphid control and yield improvement.⁴

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DAF Qld (2012) Barley planting, nutrition, 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

DAF Qld (2013) Barley planting disease guide 2013 QLD and NNSW. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/ data/assets/pdf_file/0018/53019/barley-planting-disease-quide.pdf

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

DAF Qld (2013) Barley planting disease guide 2013 QLD and NNSW. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/ data/assets/pdf_file/0018/53019/barley-planting-disease-guide.pdf

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February 2016

Some seed treatments contain triazole fungicides (triadimenol and triadimefon). These seed treatments can reduce coleoptile length, and the degree of reduction increases as the rate of application increases.

Recent research with barley has shown that the highest registered rate of triadimenol can reduce emergence, and that the reductions are greatest in varieties with short coleoptiles when sown at depths greater than 50 mm. The 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.⁵

3.1.1 Choice of seed or in-furrow treatments

All barley crops should be treated with a product that controls powdery mildew. Use of imidacloprid for aphid and mite management has become common and it may affect the choice of fungicide delivery, i.e. growers are more likely to use a seed treatment than in-furrow fungicides.

Current seed treatments for the control of net form of net blotch are effective only for seed-borne inoculum and not for stubble-borne inoculum. The level of control of seed-borne infection is also not complete. Where growers think that they may have a problem with seed-borne infection, it is recommended they have the seed tested by the cereal pathology group at the <u>South Australian Research and Development Institute</u>. ⁶

Systiva® (active ingredient fluxapyroxad), a new BASF product, is a seed-applied fungicide that provides longer term control of foliar diseases.

3.2 Time of sowing

Sowing too early increases the risk of frost damage; sowing too late will increase protein and screenings. ⁷Early planting can also increase the risk of net-blotch infection, which requires a timely funcicle program.

Factors to consider with regard to planting time:

- Sowing at the right time is critical for optimising grain yield and can 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 it experiences a
 warm late autumn or warm early winter; variety choice can be important here.
- Later maturing and shorter stature varieties are preferred for early planting to avoid tall, lush early growth.
- At flowering, barley can tolerate a frost temperature 1°C lower than wheat.
- A frost of –4°C at head-height during flowering can cause 5–30% yield loss; barley is more susceptible than wheat to frost at grainfill.
- A frost of -5°C or lower at head-height can cause 100% yield loss.
- A strongly negative April–May Southern Oscillation Index is a good indicator of late frosts
- Hot and dry weather during spring can reduce the grainfill period and affect yield and grain size, particularly if night temperatures do not fall below 15°C.



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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

H Wallwork (2014) Cereal Seed Treatments 2014. SARDI, http://www.naturalresources.sa.gov.au/files/715d15f9-3801-41f4-b30f-a35d00d1df6a/cereal-seed-treatments-for-2014-gen.pdf

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



Later planting and later flowering generally result in declining yield potential due to higher temperatures and moisture stress during flowering.^{8 9}

Sowing time determines when a crop matures, and ideally, flowering and grainfill should be in the cooler part of spring. Sowing on time maximises the chances of achieving high yields and malting grade. Sowing after mid-June usually limits yield potential and results in smaller grain and higher protein, rendering the grain less likely to be accepted as malting.

Aim to sow in the earlier part of the indicated optimum time to achieve the maximum potential yield (Table 1). Selection of the actual date should allow for soil fertility and the risk of frost damage in particular paddocks. ¹⁰

Table 1: Barley time of sowing guide.

This table is a guide only and has been compiled from observations of the breeder and local departmental agronomists. >, Earlier than ideal; X, optimum sowing time; <, later than ideal but acceptable

Mallee	April			M	ay			Ju	ne			Ju	ly		
Baudin(1), Gairdner, Wimmera(1)		>	Χ	Χ	Χ	Χ	Χ	<	<						
Commander(D, Compass(D, Fathom(D, Fleet(D, Keel		>	Χ	Χ	Χ	Χ	Χ	Χ	<	<	<				
Buloke ⁽¹⁾ , Hindmarsh ⁽¹⁾ , La Trobe ⁽¹⁾ , Scope ⁽¹⁾ , Skipper		>	>	Χ	Χ	Χ	Χ	Χ	<	<					
Wimmera	April			M	ay			Ju	ne			Ju	ly		
Flinders©, Gairdner, GrangeR®, Navigator®, Oxford, Wimmera				>	Χ	Χ	Χ	Χ	Χ	<	<				
Keel				>	>	Χ	Χ	Χ	Χ	Χ	Χ	Χ	<	<	
Baudin(t), Fleet(t)				>	>	Χ	Χ	Χ	Χ	Χ	Χ	<	<		
Fathom(b, Hindmarsh(b, La Trobe(b, Skipper				>	Χ	Χ	Χ	Χ	Χ	Χ	Χ	<	<		
Buloke(h, Commander(h, Compass(h, Scope(h						>	Χ	Χ	Χ	Χ	Χ	<	<		
North central	April			M	ay			Ju	ne			Ju	ly		
Flinders©, Gairdner, GrangeR©, Navigator®, Wimmera®			>	>	Χ	Χ	Χ	Χ	Χ	Χ	<	<			
Fleet(1)				>	>	>	Χ	Χ	Χ	Χ	Χ	<	<		
Buloke ⁽¹⁾ , Commander ⁽¹⁾ , Compass ⁽¹⁾ , Scope					>	>	Χ	Χ	Χ	Χ	<	<			
Fathom(b, Hindmarsh(b, La Trobe(b, Skipper				>	Χ	Χ	Χ	Χ	Χ	Χ	Χ	Χ	Χ	<	<
Keel						>	>	Χ	Χ	Χ	Χ	Χ	Χ	<	<
North east	April			M	ay			Ju	ne			Ju	ly		
Flinders©, Gairdner, GrangeR®, Navigator®, Oxford, Wimmera			>	Χ	Χ	Χ	Χ	Χ	Χ	<	<				
Baudin				>	>	Χ	Χ	Χ	Χ	Χ	<	<			
Keel					>	>	Χ	Χ	Χ	Χ	Χ	Χ	Χ	<	<
Buloke ⁽¹⁾ , Commander ⁽¹⁾ , Compass ⁽¹⁾ , Scope ⁽¹⁾						>	>	Χ	Χ	Χ	Χ	<	<		
Fathom(l), Hindmarsh(l), La Trobe(l), Skipper					>	Χ	Χ	Χ	Χ	Χ	Χ	Χ	<	<	
Fleet						>	>	Χ	Χ	Χ	Χ	Χ	<	<	

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



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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





GRDC Update Papers:

Management effects
on barley varieties—
nitrogen management
and time of sowing

South West	April		Ma	ay			Ju	ne			July
Baudin(b, Capstan(b, Gairdner, GrangeR(b, Navigator(b, Oxford, Westminster(b, Wimmera(b)		>	>	X	X	X	X	Х	<	<	<
Commander(l), Compass(l), Fathom(l), Fleet(l), Hindmarsh(l), La Trobe(l)				>	>	X	X	Х	Х	<	<

FAQ 3.3 Targeted plant population

3.3.1 Seeding rates

Seeding rate is the amount (in kg) of seed needed to plant in order to establish the target plant population. To determine seeding rate you need to know the target plant population, the number of seeds per kg, the germination percentage of the seed and the likely field establishment.

The number of seeds per kg will vary depending on variety and the season in which the seed was produced. To calculate this figure, count the number of seeds in a 20-g sample and multiply by 50. Newer varieties tend to have larger seed and it is important to take note of this when determining planting rate. ¹¹

Seeding rates that are too high may reduce grain size and increase lodging, especially under irrigation; seeding rates that are too low will reduce yield potential.

Lower rates should be used when there is limited subsoil moisture at sowing, and in drier areas. High seeding rates tend to decrease grain size and increase screenings in barley. ¹²

3.3.2 Plant population

Although barley can produce a large number of tillers, best yields will be achieved with an established plant stand of 80–120 plants/m². Barley can tolerate quite high plant populations without significant yield reductions; however, if plant populations fall below 80 plants/m², yield can be reduced. Lower plant populations can also encourage excess or late tillering, resulting in a less even crop and delayed harvest. Late tillers often have smaller seed, which also affects the quality of the crop.¹³

Plant population is influenced by seeding rate, row spacing and emergence percentage. Target plant populations vary with yield potential, seasonal conditions and sowing date. Current recommendations for southern regions range from 120 to 200 plants/ m^2 , depending on variety and rainfall zone. When populations fall below 50 plants/ m^2 , yield is affected. At <30 plants/ m^2 , the paddock should be resown unless it is undersown with a legume.

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:

- soil moisture
- sowing date: higher rates with later sowings (tiller capacity is more limited with later sowings)
- seed germination percentage
- seed size

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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

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

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



- seedbed conditions
- tillage (e.g. increase sowing rate with no-till)
- soil fertility (increase sowing rate with increasing yield potential)
- soil type (e.g. crusting)
- field losses (e.g. increase sowing rate if there is a problem with insects)

Appropriate seeding rates are important in barley for both grain yield and grain quality. Trials at Rankins Springs, New South Wales, in 2005 showed that yield increased with seeding rate up to about 120 plants/m² in most varieties, whereas kernel weight decreased with each increase in plant density for all varieties.

Retention also decreased with increases in plant density in all varieties except Buloke(), although the decline was only minor in Schooner. The effect of grain shape was evident. Buloke() had the heaviest grains but was intermediate for retention, whereas Baudin() had high retention values and the lowest kernel weights. High seeding rates should be avoided in Gairdner. ¹⁴

3.3.3 Calculating sowing rate

To achieve total ground cover and establish the foundation for maximum yield, a crop density of 120–200 plants/m² is needed.

Sowing rate can be calculated by knowing the seed weight, germination percentage and the required plant density. For example, with barley seed with seed weight 4.5 g/100 seeds, germination percentage 95%, and required plant density 170 plants/m²: sowing rate = $4.5 \times (10/95) \times 170 = 80.5 \text{ kg/ha}$. ¹⁵

An alternative formula is: sowing rate = (plants/ m^2 x 1000-seed weight/100) \div (establishment % x germination %)

Crop establishment

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

- seedbed moisture
- seed–soil contact
- high temperatures
- disease
- soil insects and soilborne diseases
- depth of planting (may be inaccurate or variable)
- · certain seed treatments that reduce coleoptile length
- herbicide residues
- germination and vigour of the seed

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

Surface sealing may be a problem if heavy rains fall immediately after sowing and prior to emergence. The emerging shoot is often unable to penetrate the hard surface crust that forms as the soil dries. The problem is more prevalent on soils with declining organic matter, especially red-brown earths and grey clays. Gypsum application may help alleviate this problem on hard-setting clays. ¹⁶

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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

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

information

GRDC: Crop placement and row spacing—

Southern Fact Sheet



February 2016

Establishment depends on seedbed conditions, soil moisture, presence of insect pests, and climate. Establishment percentage is the percentage of seed planted that establishes on planting moisture. Establishment may be as high as 95% under ideal conditions, or drop to as low as 40% with rough seedbeds, early planting and limited moisture. ¹⁷

How to measure your plant population

Here is a simple way to check the plant population in your 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. ¹⁸

3.3.4 Row-spacing effects

The depth of seed placement and the distance from the adjacent row both influence crop performance. With greater uptake of no-till and precision farming, the opportunities to vary row spacing by crop and to sow on the inter-row have increased. However, increasing row spacing is not always beneficial to yield.

Row spacing is a compromise between:

- ease of stubble handling;
- optimising seedbed utilisation and travel speed;
- managing weed competition and soil throw; and
- achieving effective use of pre-emergent herbicides.

Although row spacing is relatively simple to change, the effect on the whole-farm system can be complex. A change can influence yield, time of sowing, machinery choice and setting, herbicide type, seed costs, and fertiliser type and timing. Using different row spacing for different crop types will influence the types of crops sown and their sequence in the rotation.

Effect on yield

The higher the yield potential, the greater the negative impact of wide rows on cereal yields.

The impact of row spacing on yield varies depending on the growing-season rainfall. In trials in the Victorian Mallee, wide row spacing at 30 cm has been shown to improve yields of wheat and barley slightly where the yield potential is low (<1 t/ha). Other trials on wide row spacing and the effect on yield in cereal crops with low yield potential (1–2.5 t/ha) have been inconclusive.

Generally, increasing row spacing up to 30 cm has no effect on wheat yield when yield potential is <3.5 t/ha. In higher rainfall zones, where yields are >3.5 t/ha, significant yield decreases have been recorded in crops with wider row spaces.

Trials conducted over three consecutive years by <u>Southern Farming Systems</u> near Geelong, Victoria, have shown that row spacing of 40 cm reduced wheat yield by \sim 6% compared with row spacing of 20 cm.

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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

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



3.4 Sowing depth

Barley does not tolerate waterlogging, so good paddock drainage and management are essential for high grain yields. ¹⁹

Pay close attention to sowing depth, particularly when direct-drilling and for varieties with a short coleoptile. The ideal depth is 3–6 cm for sowing into moist soil. If dry sowing is being considered, target a sowing depth of 3–4 cm, particularly on a hard-setting or slumping soil, to avoid problems with crop emergence.

Sowing depth is the key management factor for uniform, rapid emergence and establishment. 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. The coleoptile may stop growing before it reaches the soil surface, and the first leaf then emerges from the coleoptile while it is still below the soil surface. The leaf is not adapted to pushing through soil, so it usually buckles and crumples, failing to emerge and eventually dying. ²⁰

A few tips:

- Avoid the shorter coleoptile (dwarf) varieties.
- Avoid seed dressings that contain triadimenol, which can shorten the coleoptile and make emerging from depth more difficult.
- Try to minimise the amount of soil placed back over the top of the planting furrow. 21

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3.4.1 Barley varieties differ in coleoptile length and emergence from deep sowing²²

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 depth greater than ideal. This study measured the emergence of up to 12 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 emerging, 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 at shallow depths when using varieties that have short coleoptiles and to take care with seed grading and the use of seed dressings.

Dubbo Update 2010—seeding depth responses

Twelve barley varieties were sown at three depths (44, 87, and 112 mm of soil above the seed) at Condobolin in 2008, using seed from a common 2007 site. Seed was graded

- 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
- 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
- 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
- NA Fettell. Agricultural Research & Advisory Station, Condobolin, University of New England.



Hart Field Site: Trial results 2013 (pp. 16–19)

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

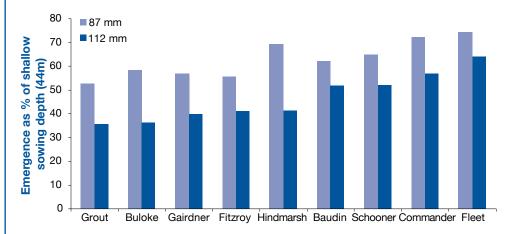


Figure 1: Plant emergence for medium (87 mm) and deep (112 mm) sowing as a percentage of the emergence from shallow (44 mm) sowing, 2008.

The experiment was repeated in 2009, using seed from a common 2008 site, but without the three seed-size treatments. Sowing depths 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 more similar. At both 77 and 101 mm, Fleet() showed the least reduction in emergence, followed by Buloke(), Commander() and Schooner. Hindmarsh() and Grout() showed the poorest emergence, particularly from 101 mm. The variety responses were generally similar to 2008 with the exception of Buloke(), which performed much better in 2010.

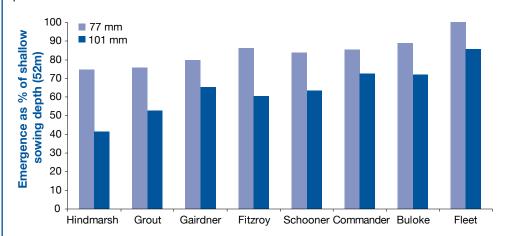


Figure 2: Plant emergence for medium (77 mm) and deep (101 mm) sowing as a percentage of the emergence from shallow (52 mm) sowing, 2009.

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



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coleoptiles were sown at 87 or 112 mm, resulting in emergence values only 20-40% of those for untreated seed.

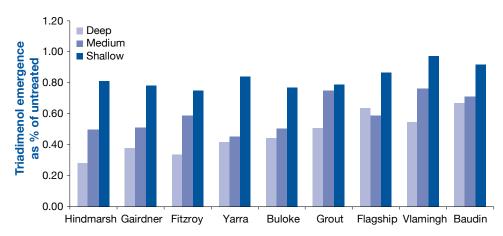


Figure 3: Plant emergence of triadimenol treated seed as a percentage of the emergence of untreated seed, compared at shallow (44 mm), medium (87 mm) and deep (112 mm) sowing in 2008.

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.

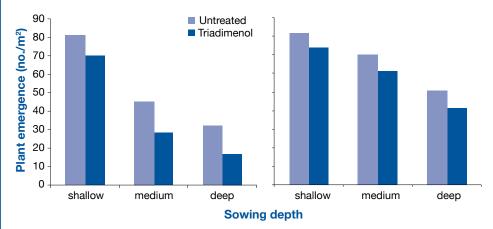


Figure 4: Plant emergence from untreated and triadimenol-treated seed, averaged over 12 varieties, in 2008 (left) and 2009 (right).

3.5 Sowing equipment

During the shift from conventional farming systems to no-till farming systems, the effective use of herbicides has become increasingly important. A well-planned herbicide strategy, in conjunction with non-chemical control methods, can mean the difference between no-till succeeding or not.

Over the past 5–6 years, it has become apparent that the rapid change in farming systems has overtaken farmer knowledge on how to use many herbicides in conservation farming systems. Older, more traditional herbicides that were designed for use in cultivated systems can still be used very effectively in no-till systems; however, they are usually used in a different manner. In addition, many herbicide labels (especially older type or generic herbicides) have the same content now as they did 10–15 years ago. Some products with generic counterparts even have quite different label claims for the same active ingredient. This creates many problems for farmers and agronomists wanting to use these herbicides in modern, no-till farming systems.



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Residual herbicides at sowing are very effective for controlling a wide range of weeds, both in-crop and well into the following summer. Some residual herbicides also have valuable knockdown properties. This is very useful because knockdown herbicide options prior to sowing are limited for hard-to-kill weeds.

Knowing the chemistry and mode of action of each herbicide is vital to enabling the best combination of crop safety and weed control. Heavy rainfall just after sowing, when combined with certain soils, can lead to crop damage.

Some herbicides are mobile with soil water, and others are less mobile. Mobility can also change with time for particular herbicides. In the case of Boxer Gold®, the longer it is allowed to bind to soil particles, the less chance there is of the herbicide becoming mobile in the soil. Other herbicides such as Logran® are mobile regardless of binding period.

The incorporated-by-sowing (IBS) application technique appears the safest way of using most residual herbicides, because the seed furrow is left free of high concentrations of herbicide. The soil from that furrow is thrown on the inter-row, where it is needed the most. 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 with IBS application are achieved 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. 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 vary greatly in their ability to incorporate herbicides effectively. There are many tine shapes, angles of entry into the soil, breakout 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, residual herbicide incorporation is variable between seeders. There are therefore no rules of thumb for sowing speed, row spacing and soil throw. You must check each machine in each paddock.

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 presswheels 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 they are therefore not preferred for IBS application. Knife-points and presswheels do a much better job. ²³

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

3.5.1 Using pre-emergent herbicides with different seeding equipment

Seeder design has changed dramatically in recent years, aiming to maximise trash flow and seed placement uniformity while minimising soil disturbance. This has led to increased uptake of knife-point and press-wheel seeders and, more recently, disc seeders.

More information

GRDC Update Papers: Options for using more residual herbicides in northern no-till systems

GRDC Fact Sheets: Stubble management

> B Haskins (2010) Residual herbicides at sowing using disc and tyne no till seeding equipment. Riverine Plains, http://riverineplains.com.au/ literature 53801/Residual Herbicides - Barry Haskins





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Each seeder will create a different environment for an establishing crop, and it is essential to understand this before using pre-emergent herbicides. Furthermore, this environment may change with IBS or PSPE incorporation methods. In general, a great deal of difference is achieved for crop safety between seeders in IBS systems, and less difference in PSPE application methods. The PSPE technique relies on uniform seeding depth and flatter seedbeds without pronounced furrows. The focus here is on the IBS method of incorporation, this method being preferred in conservation-farming systems.

Pre-emergent herbicides that are incorporated by sowing require the sowing process to ensure that they are incorporated effectively and that the seed is placed into a micro-environment that allows safe and effective germination. In all cases, the ideal situation is using a knife-point or disc followed by a press-wheel. Press-wheels provide the seed with good soil contact, and minimise the amount of herbicide-treated soil from the inter-row being dragged into the seed furrow. They also allow seeders to pass through stubble without the machine becoming choked with trash. All seeding gear is different, which, in turn, creates varying seedbed conditions.

In tined seeders, variations include:

- · angle of tine entry to the soil
- soil-throw
- width and shape of seeding point
- · breakout pressure of tine
- · depth uniformity across machine
- trash flow ability across machine
- · press-wheel size and shape

In disc seeders, variations include:

- ability to penetrate compacted soils
- ability to achieve controlled soil-throw onto the inter-row
- · angle of disc entry to the soil
- · size, shape and width of disc
- seed placement in furrow, i.e. bottom or side
- closing plates or closing wheels that allow consistent closure of the seed slot without returning herbicide-treated soil onto the seed
- depth gauge wheel placement and size
- press-wheel angle, size and shape

Other factors not associated with the type of seeding system also influence seedbed conditions. These include soil type, soil moisture, soil compaction, row spacings, seeding depth and sowing speed.

There is no rule-of-thumb for soil throw, row spacing and sowing speed because of the variability discussed above. The only way to check for adequate soil throw is to check every scenario.

The suitability for pre-emergent herbicides in both tine- and disc-seeding systems has attracted much research over the past few years. Unfortunately, many herbicide labels will not support the use of some pre-emergent herbicides with disc seeders because of the greater risk of crop damage arising from the varying machine designs that form very different seedbed conditions.

Irrespective of the disc seeder, research in southern New South Wales 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.



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As shown in Figure 5, this research has also demonstrated that some herbicides and rates of a particular herbicide are better suited to a disc-seeder system than are others. This is usually correlated with how a seedling metabolises a particular herbicide if they contact each another. Figure 5 demonstrates that trifluralin at higher rates is not suited to disc-seeding systems, because crop vigour may be adversely affected. ²⁴

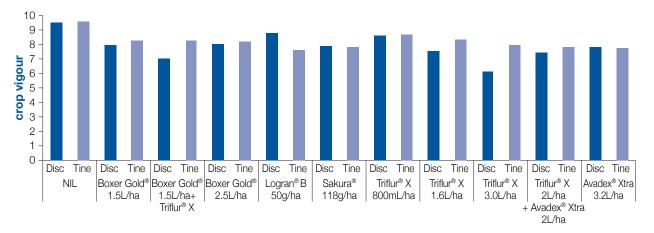


Figure 5: Difference in crop safety between discs and tines across a number of commonly used, pre-emergent herbicides in trials held across southern and central NSW. Various disc and tine seeders were used for these trials. 0, No crop vigour; 10, vigorous crop.



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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/Usingpre-emergent-herbicides-in-conservation-farming-systems.pdf



SECTION 4

Plant growth and physiology

4.1 Germination and emergence

4.1.1 Germination

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

- water absorption (imbibition)
- activation
- visible germination

Phase 1: Water absorption (GS01*)

(*See under heading 'Plant growth stages' below for detail on Zadoks Cereal Growth Stage Key)

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. ¹

4.1.2 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 or the first leaf becomes visible above the soil surface.

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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



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.

4.2 Factors affecting germination and emergence

4.2.1 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. ²

4.2.2 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 5 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 moisture 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 and/or lime may 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





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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 amount of organic matter, which improves the stability of the soil by binding the soil particles together. $^{\rm 3}$

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

4.3.1 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.

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 (see Table 1). For example, at an average temperature of 7°C, it takes 5 days for visible germination to occur; at 10°C, it takes 3.5 days. Other examples are presented in Table 2.

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

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

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 that 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. Barley cultivars differ in coleoptile length, but this characteristic is not closely linked to plant height or to dwarfing genes.

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 centimetres 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.



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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



Table 3 shows the average number of plants that established with increasing soil temperatures. Seed at 100 kg/ha was planted at a depth of 30–40 mm. The soil temperature was measured in the field at a depth of 50 mm.

Table 4: Number of plants established at various soil temperatures
The difference between 20.2°C and 33.2°C is statistically significant ⁴

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

4.3.2 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. ⁵

4.3.3 Seed quality

Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if seed is undamaged, stored correctly and from a plant that had adequate nutrition. Seed grading is an effective way to separate good-quality seed of uniform size from small or damaged seeds and other impurities.

Seed size is also important—the larger the seed, the greater the endosperm and starch reserves. Therefore, although size does not alter germination, bigger seeds have faster seedling growth, a greater number of fertile tillers per plant and potentially higher grain yield.

Seed size is usually measured by weighing 1000 grains, known as the 1000-grain weight. The 1000-grain weight varies among varieties and from season to season. This indicates that sowing rates need to vary according to the 1000-grain weight for each variety and in each season in order to achieve desired plant densities.

Some seed treatments can delay emergence by slowing the rate of germination, and others, which contain triazole fungicides, can shorten the length of the coleoptile. Some treatments can also shorten the length of the first leaf and the sub-crown internode. ⁶

4.3.4 Coleoptile length

Some tall varieties (e.g. Buloke(1)) have short coleoptiles, whereas some short varieties (e.g. Baudin(1)) have relatively long coleoptiles. Sowing seeds deeper than the coleoptile length will result in the coleoptile not reaching the surface, making plant emergence unlikely. Deeply sown seeds also lack early vigour, and tillering can be delayed.

In research at Condobolin, New South Wales, in 2008, plant emergence was shown to decrease with deeper sowing and was dependent on variety. When plants were sown

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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

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

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



at 87 mm depth, emergence was 50–80% of that sown at a shallow 44 mm. For plants sown at 112 mm, emergence was 35–60% of that with sowing at 44 mm. 7

4.3.5 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.

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. ⁸

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. For example, the soil needs to be moist when anhydrous ammonia is applied so it is sealed within the soil.

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 \sim 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 grain-filling 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 you are trying to meet malt specifications, use the crop for grazing, or maximise the yield of a feed variety. 9

Phosphorus

Phosphorus (P) is essential to seed germination and 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. Many of the soils in southern Australia have very low levels of available P, and in some areas it is the limiting nutrient.

Unlike N, P is relatively immobile in the soil; therefore, it needs to be placed near the seed. Regardless of soil test results, some P needs to be applied with seed at sowing.

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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

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

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



One method of estimating P requirement is to allow 4 kg P per tonne (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. ¹⁰

4.4 Plant growth stages

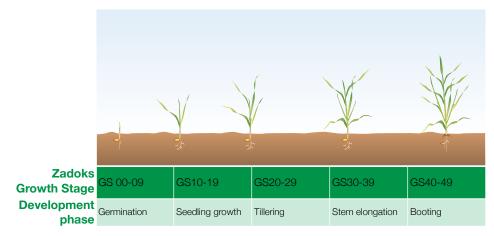
4.4.1 Plant growth stages

A growth stage key provides farmers, advisers and researchers with a common reference for describing the crop's development. Management by growth stage is critical to optimise returns from inputs such as N, plant growth regulators, fungicides and water.

4.4.2 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.



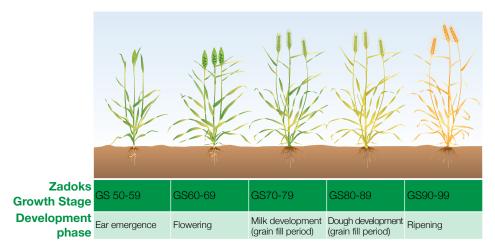


Figure 1: Zadoks growth stages. 11



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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

N Poole (2005) Cereal growth stages guide. GRDC, http://www.grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf





Early stem elongation GS30-33 (pseudostem erect—third node on the main stem)

This period is important for both timing of N application and protection of key leaves. 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. 12

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



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N Poole (2005) Cereal growth stages. Grains Research and Development Corporation, http://www.grdc. com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf



SECTION 5

Nutrition and fertiliser



More information

BCG: Current GRDCfunded projects. More Profit for Crop Nutrition (MPCN II): Extension and training (Southern Region)

GRDC: Crop nutrition news

GRDC Fact Sheets: Better fertiliser decisions for crop nutrition

GRDC Update Papers: Making variable rate application a success on your farm

GRDC Update Papers: Assessing canopy management in CTF systems with farmer machinery

GRDC Update Papers: Current nutrition issues in the cropping zone of Southern Australia

GRDC Ute Guide: Winter cereal nutrition

NSW DPI: BFDC Interrogator

Research paper: Nitrogen management: a key driver of farm business profit and risk in the low rainfall Mallee



More information

GRDC Update Papers: Soil organic matter what is it worth to grain production and what practices encourage it

Research & Development

Corporation

With the more frequent use of opportunity cropping, improved farming techniques, and higher yielding varieties, nutrition programs should be reviewed regularly.

Nutrient deficiencies are common for nitrogen (N), phosphorus (P), potassium (K) and zinc (Zn). Sulfur (S), copper (Cu), manganese (Mn) molybdenum (Mo) may be 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 comparable to those of wheat without necessarily producing a protein level above that acceptable for malting specifications. 2

Management of N availability is vital to achieving optimal yields and quality in your barley crop. Unlike wheat, which attracts premiums for high protein, malting barley can attract a premium if protein falls 9-12%. A protein target of 12% will also maximise a barley crop's yield potential. 3

When fertiliser prices peaked in 2008, questions were raised about the cost effectiveness of these inputs. New information was sought on best practice for yield and profitability. The result was the Grains Research and Development Corporation's (GRDC) More Profit from Crop Nutrition initiative. 4

To read about progress made under the program, download: Ground Cover Issue 97 Supplement: More profit from nutrition.

Organic matter 5.1

Organic matter has a fundamental role in soils. It 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 waterholding 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.

- 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
- 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
- DAF Qld (2012) Barley planting, nutrition and harvesting. Department of Agriculture and Fisheries, planting-nutrition-harvesting
- 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

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5.2 Declining soil fertility

The natural fertility of cropped agricultural soils can decline over time. Grain growers must continually review their management programs to ensure the long-term sustainability of high-quality grain production. Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils (Figure 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.

Although crop rotations with pulses and ley 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. ⁵



Figure 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 enough N if P or Zn deficiency is limiting yield. To make better crop nutrition decisions, growers need to consider the use of paddock records, soil tests and fertiliser test strips. This helps to build an understanding of which nutrients the crop removes at a range of yield and protein levels.

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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



The use of paddock grain protein to detect N deficiency is well established for wheat and barley. Grain protein lower than these levels is likely to indicate loss of yield due to inadequate N supply. 6

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. 7

More information

GRDC Update Papers: Making variable rate application a success on your farm

GRDC Update Papers: Assessing canopy management in CTF systems with farmer machinery

GRDC Update Papers: Subsoil manuring

5.3.1 Paddock records

Paddock records help to:

- establish realistic target grain yield and protein levels prior to planting
- modify target yield and protein levels based on previous crop performance (yield and protein), planting soil moisture, planting time, fallow conditions, expected incrop 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. 8

5.4 Understanding soil pH

A soil pH in calcium chloride (CaCl₂) 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 pHCa <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. 9

At low pH, beneficial elements such as Mo, P, Mg, S, K, Ca, and N become less available and others may become toxic (Figure 2). Maintain soil pH(CaCl₂) at 5.5-6.5 to achieve maximum P availability for cereals. 10

Lime can be applied to increase low pH levels. The pH-mapping process can deliver immediate lime savings of 20-60%, with an average saving of 30%. A 10% lime saving is generally required to cover the cost of the mapping process. ¹¹ See more in the GRDC Update Paper: pH-mapping and variable rate lime — 50,000 plus hectares of experience.



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

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

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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

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

A Whitlock (2015) pH mapping and variable rate lime. GRDC Update Papers, 27 August 2015, http://www. grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/pH-mapping-and-variable-ratelime-50000-plus-hectares-of-experience



For more information on crop-specific reactions to soil pH levels, download the NSW Department of Primary Industries leaflet: <u>Understanding soil pH.</u>

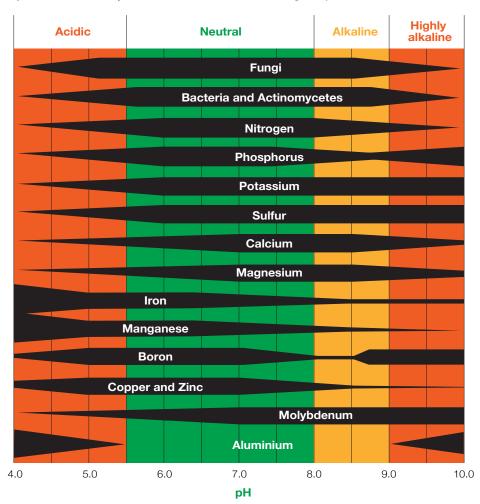


Figure 2: Availability of nutrients and other elements varies with soil pH.

5.4.1 Soil pH in calcium chloride

This is the standard method of measuring soil pH in southern Australia. An air-dry soil sample is mixed with five times its weight of a dilute concentration (0.01 m) of CaCl₂, shaken for 1 h, and the pH is measured by using an electrode. The results are usually expressed as pH(CaCl₂).

5.4.2 Soil pH in water

Distilled water is used instead of 0.01 m $CaCl_2$, and results are expressed as pH(H2O). The pH(CaCl_2) test is the more accurate of the two tests, because it reflects what the plant experiences in the soil. The values of pH(CaCl_2) are normally lower than pH(H2O) by 0.5–0.9. A useful, but not consistently accurate, conversion is to subtract 0.8 from the pH(H2O) to obtain a pH(CaCl_2) value. The difference between the methods can be significant when interpreting results and it is important to know which method has been used, especially if pH values derived some years apart are being compared to assess fluctuations. 12



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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



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. ¹³

Additive effects of N and P appear to account for most of the above ground growth and yield response. $^{\rm 14}$

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 3). ¹⁵



Figure 3: 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 ¹⁶

		N	P			K	;	S
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble
Barley	20	7	2.5	0.7	4.5	18	1.5	1.5
Wheat	21	8	3	0.7	5	21	1.5	1.5

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 them.

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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

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

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

P Parker (2009) Nutrition and soil fertility. Canola Best Management Guide. GRDC, http://www.australianoilseeds.com/ data/assets/pdf file/0011/8021/77 GRDC Canola Guide Nutrition and soils.





Research paper:
Assessment of subsoil salinity and sodicity constraints to barley and faba bean production

Temperature and soil moisture content affect the availability of nutrients to plants, and 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. ¹⁷

5.7 Soil testing

Soil testing and professional interpretation of results should now be an integral part of all management strategies. Soil tests estimate the amount of each nutrient available to the plant rather than the total amount in the soil. Valuable information obtainable from a soil test includes current nutrient status, acidity or alkalinity (pH), soil salinity (electrical conductivity, EC) and sodicity (exchangeable sodium percentage), which can affect soil structure.

Soil test information should not be used alone to determine nutrient requirements. It should be used in conjunction with test-strip results 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.¹⁸

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

Soil test results are part of the information that supports decisions about fertiliser rate, timing and placement. However, to determine micronutrient status, plant tissue testing is usually more reliable.

5.7.1 Types of test

The soil tests for measuring N, P, K or S in the Southern Region are:

- bicarbonate-extractable P (Colwell-P)
- · diffusive gradients in thin-films (DGT) for P
- bicarbonate-extractable K (Colwell-K)
- KCI-40 extractable S
- 1 m KCl-extractable inorganic N, which provides measurement of nitrate-N and ammonium-N



GRDC: Soil testing for crop nutrition (Southern Region)

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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

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



For determination of crop N requirement, soil testing is only one part of the picture. Soil N availability and crop demand for N are both highly influenced by seasonal conditions.

Other measurements that aid the interpretation of soil nutrient tests include soil pH, percentage of gravel in the soil, soil organic matter content, P sorption capacity (currently measured as P buffering index, PBI), EC, chloride and exchangeable cations (CEC), including aluminium (AI).

5.7.2 Sampling depth and achieving representative samples

Soils must be sampled to the correct depth. Sampling depths of 0–10 and 10–60 cm are generally used. The 0–10 cm sample should be used for a comprehensive soil test (all nutrients, cations, pH, EC, sodium). The 10–60 cm sample (or known rooting depth) is more commonly used to determine levels of N, S, EC and B (or other nutrient constraints) and moisture.

Sulfur testing at 0–10 cm is not as indicative of crop needs as 0–60 cm; this is more so on sandy soils where leaching of S from the topsoil readily occurs.

If subsoil constraints are suspected, pH, EC, sodium and chloride are tested at intervals (e.g. 30 cm) to 120 cm where possible. There is increasing evidence of the value of assessing soil-based physicochemical constraints to production, including sodicity, salinity and acidity–AI, from both the surface and subsoil layers.

To ensure that a sample is representative:

- Check that the soil type and plant growth is typical of the whole zone or paddock.
- Avoid areas such as stock camps, old fence lines and headlands.
- Ensure that each subsample is taken to the full sampling depth.
- Do not sample in very wet conditions or within 2 weeks after significant summer rain.
- Do not take shortcuts in sampling, such as taking only one or two cores, a handful, or a spadeful of soil; this will give misleading results.
- Avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers or other sources of nutrients (e.g. sunscreen, which can contain Zn).

5.7.3 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 (Table 2).

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. Growers must exercise judgement about the costs and benefits of adding fertiliser in the forthcoming season versus those associated with no application.

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. ¹⁹



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GRDC (2014) Soil testing of crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS



Table 2: Critical values and critical ranges (mg/kg) of Colwell-P for the 0-10 cm sampling layer for 90% of relative yield 20

Soil types are based on the Australian Soil Classification. For phosphorus, insufficient data are available to provide calibration criteria for diffusive gradients in thin-films (DGT)-P (check BFDC Interrogator). Insufficient sulfur data to measure 0-10 cm

Soil test	Crop	Soil type	Critical value	Critical range
Colwell-P	Wheat and	Vertosols	17	12–25
	barley	Chromosols, Sodosols	22	17–28
		Brown/Red Chromosols	25	18–35
		Calcarosols	34	26–44
	Barley	Ferrosols	76	46–130
	Canola	All soils	18	16–19
	Field pea	All soils	24	21–28

Fertiliser test strips

Test strips within the paddock allow you to fine-tune the fertiliser program. 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.

When setting up a test-strip area:

- Ensure that you can accurately locate the strips—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 that the test strip area is ~100 m long, with each strip 1–2 header widths.

A number of local **Grower Groups** conduct nutrition trials.

Colour photographs of nutrient deficiencies can be found in: Grundon NJ (1987) 'Hungry crops: a guide to nutrient deficiencies in field crops', Department of Primary Industries, Queensland Government, Information series Q187002. 21

Rules of thumb 5.7.5

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 you do not use a standard approach to sampling, a comparison of the data between different tests will not be reliable. Aim for data that have the best chance of representing the whole paddock, and mix the sample thoroughly.



Agriculture Victoria: Using fertiliser test strips on pasture

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GRDC (2014) Soil testing of crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014. http://www.grdc.com.au/GRDC-FS-SoilTestingS

DAF QId (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/





GRDC Fact Sheets: Crop nutrition phosphorus management

For monitoring, sampling should cover roughly the same area each time to ensure meaningful comparisons between years. Permanent markers on fence posts to mark a sampling transect, or a handheld GPS or your smartphone, will serve this purpose.

Soil-testing laboratories should be able to provide information on appropriate soil sampling and sample-handling protocols for specific industries and crop types. Refer to the Australian Soil Fertility Manual from CSIRO Publishing or download the GRDC Fact Sheet Better fertiliser decisions for crop nutrition. 22

Utilise an ASPAC- and NATA-accredited testing service. The results are more likely to be statistically significant and have reduced variation between tests.

5.7.6 Soil testing for nitrogen

The approximate amount of N available in the soil can be determined by soil testing. Soil tests should be taken at various places in each paddock to a depth of 60 cm or to a known rooting depth. 23 Test results are a good indication of N, but historical grain yield and protein levels from the paddock can also be used to assist N-requirement decision making. 24

Environmental conditions, including temperature, time and rainfall events can affect starting soil N; therefore, 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.

Forms of N fertiliser

Nitrogen is available in four main forms:

- 1. Nitrate, e.g. ammonium nitrate, sodium nitrate, potassium nitrate
- Ammonium, e.g. anhydrous ammonia, sulfate of ammonia, ammonium nitrate
- 3. Amide, e.g. urea
- Organic, e.g. blood and bone, meat meal

It is important to choose the right product; some compositions are more suited than others to certain conditions.

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) X 100/% N in fertiliser product 25

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).

5.7.7 Soil testing for phosphorus

Colwell-P (bicarbonate-extractable P)

The Colwell-P test uses a bicarbonate (alkaline) extraction process to assess the level of readily available soil P. It is used with the PBI to indicate the sufficiency and accessibility of P in the soil.

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

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-

DAF Old (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/

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



Soil Quality: South
Australia—phosphorus
buffering index

Research paper: A simple phosphorus buffering index for Australian soils



Soil Quality Fact
Sheet: Soil phosphorus
availability by DGT

Phosphorus buffering index

The 'buffering capacity' of a soil refers to its ability to maintain P concentration in solution as the plant roots absorb the P. The PBI indicates the availability of soil P. The higher the value, the more difficult it is for a plant to access P from the soil solution.

Soil available P by DGT (diffusive gradients in thin-films)

Present soil testing methods for assessment of available P overestimate available P on certain soil types (calcareous, acidic with high iron or Al). The DGT method has been established for assessment of available P in a wide range of Australian soils and it measures available P at more relevant chemical and physical soil conditions.

A database of DGT results with crop responses across southern Australia reveals a greater accuracy of available P measurement than with Colwell-P with or without PBI interpretation. DGT has potential not only to measure the available P status but also to predict P rates required to maximise yields in a deficient scenario.

Depth of testing for P

Soil sampling depth for most nutrient analysis (including P) is 0–10 cm. Phosphorus is relatively immobile in soils and P applied to the 0–10 cm layer generally remains in that layer, especially in no-till systems. ²⁶

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 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. For example, the critical tissue P concentration changes with the age of plants.

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. The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small (Figure 4).

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 plot harvesting of the strips can allow you to confirm whether the micronutrient was limiting. ²⁷





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GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, January 2014, https://www.grdc.com.au/~/media/34D1397472234B6F8B195732A963F047.pdf

²⁷ GRDC (2013) Micronutrients. Northern, Southern and Western Regions. Crop Nutrition Fact Sheet, GRDC, November 2013, https://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients

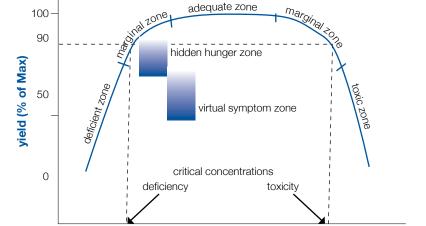


Figure 4: Generalised grain-yield response curve to plant nutrient concentration.

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Agronomy Podcasts:
Plant tissue testing-

hunger

uncovering hidden

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

GRDC Update Papers:
Legume effects on
soil N dynamics—
comparisons of crop
response to legume and
fertiliser N

GRDC Update Papers:

Management effects
on barley varieties—
nitrogen management
and time of sowing

GRDC Update Papers:
Nitrogen management—
how much is enough
and how much is too
much

GRDC Update Papers: Where does fertiliser nitrogen finish up

5.9 Nitrogen

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.

plant nutrient concentration

The pattern of crop demand for N during the growing season also has to be considered. The highest demand is when the crop is growing most rapidly. In-crop soil sampling can help to identify how much N is being mineralised. 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 are an attempt to predict the soil processes of mineralisation, immobilisation, leaching, volatilisation, denitrification and plant uptake. They are built into models such as <u>Yield Prophet</u>[®] and <u>Select Your Nitrogen</u> (SYN). Yield Prophet[®] requires a detailed characterisation of the physical and chemical properties of the soil profile explored by the roots. ²⁸



5.9.1 Southern Barley Agronomy Project and National Variety Trials

Agronomy trials were conducted in 2014 as part of the Southern Barley Agronomy Project, focusing on time of sowing, nitrogen rate and plant population decisions, with sites throughout southern New South Wales.

These trials showed the benefits to grain yield of targeting populations of 150 plants/m² across all rainfall zones. This will enhance the competitiveness of barley against weeds. Analysis of grain quality will determine whether there is a negative impact on receival standards. The combination of high plant population and high N inputs may lead to reduced yield in lower rainfall environments.

National Variety Trials were also conducted across the region. Three National Barley Trials were sown in 2014 at Gerogery, Condobolin and Parkes to determine the response of a core set of barley varieties to N rates and target plant populations across environments.

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GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS



Gerogery

This was the highest yielding of the trials. Compass to achieved the highest yield in this trial (Table 3), showing that as well as being a reliable performer in the low-medium rainfall sites, it performs well in high-yielding situations. There was no response to N in this trial (high N background) but a general yield increase in all varieties as a result of increasing target plant population from 75 to 150 plants/m² and then to 300 plants/m² (Table 3). La Trobed did not perform as well (relative to other varieties) as it did in the low-medium rainfall sites.

Table 3: Effect of variety choice and plant population on grain yield (kg/ha) of barley at Gerogery in 2014

Variety	Grain yield	Plants/m²	Grain yield
Buloke	5392	<i>7</i> 5	5169
Commander	5824	150	5528
Compass(D	6149	300	5774
Flinders	5380	I.s.d. $(P = 0.05)$	109
GrangeR(1)	5747		
La Trobe	4764		
Oxford	5603		
Westminster	5063		
I.s.d. $(P = 0.05)$	177		

Parkes

GrangeR(1) was the highest yielding variety at Parkes and Buloke(1) the lowest yielding. Grain yield increased with the application of 30 kg N/ha and increased further with application of 90 kg N/ha. There was a general yield increase in all varieties as a result of increasing target plant population from 75 to 150 plants/m² and then to 300 plants/m² (Table 4).

Table 4: Effect of variety choice, nitrogen rate, target plant population on grain yield (kg/ha) of barley at Parkes in 2014

Variety	Yield	N (kg/ha)	Yield	Plants/m²	Yield
Bass(1)	3900	0	3769	75	3805
Buloke(1)	3723	30	4087	150	4094
Commander	4167	90	4337	300	4294
Compass(1)	4090	l.s.d. $(P = 0.05)$	172	I.s.d. $(P = 0.05)$	43
Flinders	4105				
GrangeR(1)	4389				
La Trobe	4163				
Wimmera(1)	3975				
I.s.d. $(P = 0.05)$	280				

Condobolin

There were significant differences in grain yield between varieties at Condobolin, with Compass® the highest yielding variety and GrangeR® the lowest yielding (Table 5).

Table 5: Grain yield of eight barley varieties (across all nitrogen and plant population treatments) at Condobolin in 2014

Variety	Grain yield (kg/ha)
Bass(D	2002
Buloke(1)	1890
Commander	2018
Compass©	2398
Flinders(1)	2030

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Variety	Grain yield (kg/ha)
GrangeR(1)	1762
La Trobe(1)	2236
Wimmera(1)	2185
I.s.d. $(P = 0.05)$	160

There was a significant interaction between seeding rate and N rate at Condobolin (Figure 5). Increasing target seeding rate from 75 to 150 plants/m² resulted in increased grain yield at all N levels. A further plant population increase to 300 plants/m² resulted in no change in grain yield for the nil and 30 kg N/ha rates but yield was reduced at the 90 kg N/ha rate. The combination of high N rates and a high population was excessive in the relatively dry environment at Condobolin. ²⁹

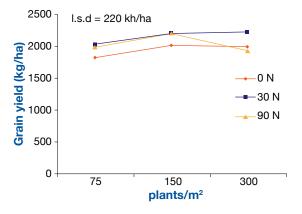


Figure 5: Interaction between nitrogen rate and plant population on grain yield of barley at Condobolin in 2014.



GRDC Update Papers: Barley agronomy in southern NSW

5.9.2 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 6) and the N cycle (Figure 7).

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P Brill, K Moore, I Menz, N Moody (2015) Barley agronomy in southern NSW. GRDC Update Papers, 10 February 2015, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Barley-agronomy-in-southern-NSW#sthash.wDtGvdXs.dpuf



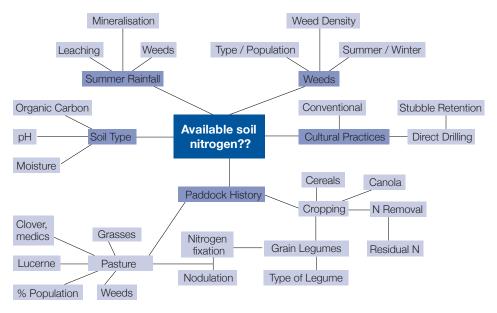


Figure 6: Factors influencing available soil nitrogen. (Source: Incitec Pivot Ltd)

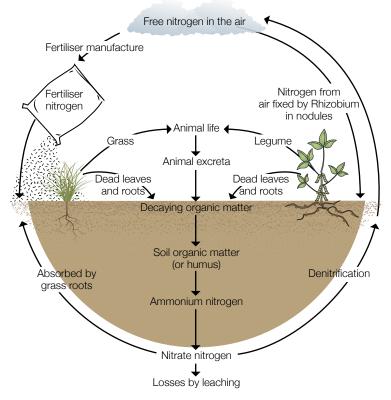


Figure 7: The soil nitrogen cycle.

Besides its role in plant growth, the availability of soil N at grainfill, along with soil moisture, is the key determinant of grain protein. The farmer has a high degree of control over N build-up and availability through the choice of crop sequences and management. 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 yield and summer rain to mineralise N can mobilise soil N for the next crop. Soil tests for N assessment should be done as close as possible to sowing time or during peak growth and at the same time each year.



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nitrogen finish up?

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cropping

N for northern grains



February 2016

Cropping advisers are a good source of support in determining fertiliser application strategies. ³⁰

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 8)). This explains why a larger proportion of the crop is of a high protein in drier seasons or seasons of low grain yield, whereas high yields can be produced but may be at a lower protein level in wetter years. Nitrogen fertility can be extremely variable from one year to the next.

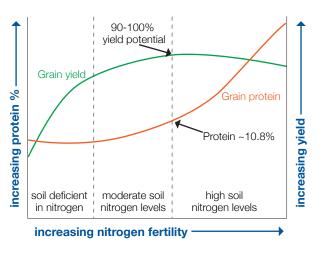


Figure 8: Relationship between grain yield and protein. (Source: Incitec Pivot Ltd)

5.9.3 Nitrogen deficiency symptoms

Description:

- Plants are pale green with reduced bulk and tiller formation (Figures 9 and 10).
- 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.



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





Figure 9: Adequate (left) and inadequate (right) nitrogen nutrition. (Photo: Mel Mason, Agriculture WA) 31



Figure 10: 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 oldest leaves, but these leaves die quickly. Reduced grain yield and protein levels may occur for other reasons.

Contributing factors

Low soil N fertility and cold wet conditions reduce mineralisation and uptake of N. Low incidence of legumes in rotation reduces amounts of N $_2$ fixed. High N loss occurs by leaching in high-rainfall areas and sandy soils. 32



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³¹ GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/ Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide

³² GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide



5.9.4 Nitrogen volatilisation and denitrification

Ammonia volatilisation can occur when urea is surface-applied without incorporation. After application, urea dissolves in water and, in the presence of urease, forms ammonium ions (NH_4 +). If there are insufficient adsorption sites at the soil surface for the ammonium ions, ammonia (NH_3) gas can form as the soil dries out, for example, in the heat of the day following overnight dew. Such losses are greatest in alkaline (highph) soils, in which hydroxyl (OH-) ions are present in high concentrations. ³³

Many farmers split the N application to barley crops between sowing, with mono- or di-ammonium phosphate (MAP, DAP), and early-mid-vegetation, with urea. Delaying N applications later in the season can affect protein requirements. Splitting N application between sowing and in-crop allows growers to lower their financial risk by allowing seasonal conditions to drive decisions on how much to spend on N, but this can come at a cost of additional yield.

Most farmers try to apply fertiliser ahead of predicted rain, but what happens if rain does not fall as predicted? Is the N all really lost to the air in a couple of days? Published international research lists the range of measured losses from 0% to almost 100%, but very few instances of losses $>\sim$ 40% of that applied, with most studies finding only \sim 10% loss.

Researchers have detailed the factors that drive the process of N volatilisation from fertiliser. The following is a brief summary of the many factors involved:

- 1. Soil pH. There is more loss at higher pH. A dissolving urea granule creates a high-pH zone.
- 2. Temperature. The hotter it is, the greater the potential for ammonia loss.
- 3. Soil moisture. Wet soil dissolves fertiliser but does not move N into the soil.
- 4. Calcium carbonate (CaCO3). Lime in the soil reacts directly with ammonium sulfate, increasing loss.
- Soil clay content. Clay in soils adsorbs ammonium-N, decreasing potential for loss.
- 6. Soil buffer capacity. Clays in soil absorb changes in soil pH.
- Biological activity. Ammonium is converted to nitrate, which is safe from volatilisation.
- 8. Wind. Windy conditions at the soil surface lead to greater loss.
- 9. Rain. Rain moves dissolved fertiliser into contact with soil clays, away from wind.
- Depth of fertiliser. Ammonia must be at the surface to volatilise. Incorporation reduces loss.
- 11. Crop canopy. Some ammonia in air can be re-absorbed by a growing crop canopy, and the canopy reduces the wind intensity at the soil surface.
- 12. Residues and litter. Residues can strand the fertiliser at the surface. Urease enzyme is present in residues.
- 13. Fertiliser type. Only the ammonium form is lost; urea converts to ammonium and nitrate forms, which are not volatilised. ³⁴

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Incitec Pivot Limited, http://www.incitecpivot.com.au/

G Schwenke, A Perfrement, W Manning, G McMullen (2012) Nitrogen volatilisation losses how much N is lost when applied in different formulations at different times. GRDC Update Papers 23 March 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Nitrogen-volatilisation-losses-how-much-N-is-lost-when-applied-in-different-formulations-at-different-times



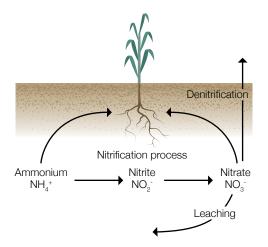


Figure 11: The nitrification process.

Saturated soil conditions between fertiliser application and crop growth can lead to significant N losses from the soil through denitrification (Figure 11). The gases lost can be nitric oxide (NO), nitrous oxide (N $_2$ O) and di-nitrogen (N $_2$). Isotope studies in the northern grains region have found that these losses can be >30% of the N applied. Direct measurements of nitrous oxide highlight the rapidity of loss in this process.

Nitrogen losses from ammonium sulfate applications were less than from urea in both bare fallows and grass-based perennial pastures. However, ammonium sulfate should be avoided on soils with naturally occurring lime in the surface. ³⁵

Research funded by GRDC and NSW DPI through a Northern Grower Alliance project (NGA0002) showed that delayed N reliably improved grain protein and maintained grain yield with applications up to early stem elongation, irrespective of the N fertiliser used. ³⁶

5.9.5 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, creating excessive early growth, causing crops to 'hay off'. Insufficient N may limit grain yield, grain protein and subsequent profitability. Within a given season in a cereal crop, fertiliser rate and timing are the major tactical tools used for N management. Applications of N at sowing or up to the start of stem elongation drive greater crop biomass and grain yield response than late applications around anthesis or Zadoks growth stage (GS) 61, which have little influence on grain yield but can drive a significant protein response. ³⁷

5.9.6 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.

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.

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adding bounce to
Mallee barley

MSF: Barley agronomy update, Karoonda Information Booklet 2013 (pp. 31–33)

MSF: Sulfur and
Nitrogen responses of
barley in Mallee 2013

Soil Quality Fact Sheet: Soil nitrogen supply

- G Schwenke (2013) Nitrogen use efficiency. GRDC Update Papers, 16 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency
- ³⁶ G Schwenke, A Perfrement, W Manning, G McMullen (2012) Nitrogen volatilisation losses how much N is lost when applied in different formulations at different times. <u>GRDC Update Papers 23 March 2012</u>, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Nitrogen-volatilisation-losses-how-much-N-is-lost-when-applied-in-different-formulations-at-different-times
- ³⁷ R Brill, M Gardner, G McMullen (2012) Comparison of grain yield and grain protein concentration of commercial wheat varieties. GRDC Update Papers, 10 April 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Comparison-of-grain-yield-and-grain-protein-concentration-of-commercial-wheat-varieties

Grains Research & Development Corporation



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5.9.7 Effectiveness of late nitrogen application

Results of a GRDC-funded Southern Farming Systems trial indicate that by applying N at GS70, neither yield nor protein was increased. This was due to the plant beginning to senesce and being unable to utilise N.

Although it may be time-saving to apply N upfront at sowing, this will result in a range of issues with canopy management, because upfront N will result in excess tillers. Therefore, there are benefits with a split application of N, for example, limited numbers of tillers, which may have better grainfill at the end of the season, especially when there is a dry finish.

However, there are risks associated with a split application. A wet season may prevent access to the paddock, resulting in an application that is later than ideal, or loss of application. Leaving N application too late may result in tiller mortality, stunted crops in waterlogged paddocks, and loss of green leaf.

Key messages:

- Apply N early (stem elongation) for yield and later (head emergence) for protein.
- Decisions on N should be made as the season unfolds because a good finish can make significant difference.
- There was no significant difference in yield or protein between the different urea treatments: urea-ammonium nitrate (UAN) and liquid urea.
- There was no significant difference between the 25 and 50 kg N/ha rates for yield; however, protein was increased at the higher rate.

Improving the efficiency of N usage is a challenge that farmers face worldwide; it is a crucial factor affecting the yield and protein levels of cereals.

Too much N may increase the susceptibility of the crop to disease pressures and inefficient water use through the production of excess canopy. However, too little N applied to a crop results in stunted yields, lower or limited protein levels and a decline in profitability. This relationship is shown in Figure 12 below. 38

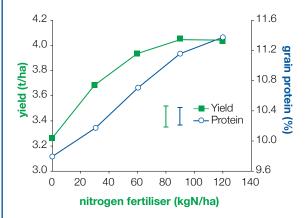


Figure 12: Grain yield (t/ha) and protein concentration (%) from 10 wheat varieties with varying rates of applied nitrogen (Brill et al. 2012).

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B Cameron. Late nitrogen in wheat: better late than never? How late is too late. Southern Farming Systems, http://www.sfs.org.au/trial-result-pdfs/Trial-Results-2013/2013_LateNitrogenInWheatBetterLateThanNeverHowLateIsTooLate-VIC.pdf



5.10 Current general in-crop nutritional levels for nitrogen

To meet malt specifications, growers should target protein levels of 10.5–12% to achieve maximum yield and still meet receival standards. 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. ³⁹



5.10.1 Barley nutrition and agronomy—do we need sulfur and nitrogen?

- Cereal requirement for S is much less than for canola.
- Responses to N are more common than to S in Mallee cereals; therefore fertiliser expenditure should reflect this.
- A balanced approach to nutrition for both S and N is required in the Mallee.
- Soil sampling at depth is critical for nutrient budgeting because S may be deficient in the top 10 cm but adequate at depth.
- Requirements for S should be locally assessed on a paddock-to-paddock basis; consider fertiliser history, cropping rotation, product removal and soil test data.
- Crops deficient in S may be recovered by in-crop applications of sulfate of ammonia.
- Levels of S may be maintained by using S-enriched fertiliser sources (i.e. gypsum).

Introduction: Why the interest in sulfur?

Nitrogen and P are considered the two most limiting nutrients for cereal crop production in the Mallee. However, supply of S is increasingly being questioned. More canola is being grown than in the past, and a shift to high-analysis P-fertiliser products containing less background S (i.e. DAP or MAP, ~1–2% S, as opposed to the previously used single superphosphate, ~11% S) has led to suggestions that S deficiency is becoming more common. As part of a GRDC-funded Barley Agronomy Project, field trials were conducted throughout the Mallee in 2012 to assess barley growth and yield responses to S on sandy soils, with respect to rate, timing, and form of S.

Importance of nitrogen and sulfur

Both N and S are involved in the formation of proteins within the plant. However, the relative crop demand for these nutrients differs. The average total N demand for cereal and canola crops is quite similar, but canola requires approximately twice the amount of S that cereals require (Table 6). Cereals typically have a grain N:S ratio of 15:1 whereas canola has a grain N:S ratio of 7:1. In cereals, lower S levels lead to lower protein and reduced flour quality, and can cause significant yield losses in deficient conditions. There is little information to support widespread yield responses to S in cereals in the Mallee; however, there are well-documented cases of S yield responses in canola.



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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



Table 6: Approximate nitrogen and sulfur requirements for cereal, pulse and canola crops (nutrient kg/ha)

Crop	Nitrogen	Sulfur
Wheat	23	1.5
Barley	20	1.4
Canola	40	5
Field peas	37	2

Decisions on N and S fertiliser

The fundamentals of fertiliser management for N and S are similar. Demand can be estimated through a budget approach. A deep soil test (10–60 cm) can be used to estimate the soil N and S content at seeding. For all budgeting equations, first determine a target yield and protein, because crop yield potential is the driver of N and S requirement. Crop N demand can then be estimated by using tools such as an N calculator, <u>Yield Prophet</u>®, and relevant calculations that factor in soil, seasonal, and soil N mineralisation.

The current recommendation for soil S testing is the KCI-40 method, which is taken in the top 0–10 cm. However, S is often located deeper in the profile. Plants take up S in the sulfate form, which is water-soluble and is mobile in the soil (like N) and readily leached. Sandy soils are generally lower in nutrients (N, S) and more prone to leaching from large rainfall events; hence the need for deep soil testing.

Sulfur responses in 2012

The 2012 trials in the Mallee demonstrated a lack of S-fertiliser response at most sites. Three of four trials showed no response to S, despite the KCl-40 (0–10 cm) soil tests suggesting levels below the critical values (4–6 mg/kg) for cereal production at all sites (Table 7). Deep soil tests revealed sufficient S in the lower soil profile. This indicates that S is more accessible later in the season when roots explore the lower profile, and may explain the lack of S response at these sites.

Table 7: Topsoil (0–10 cm) and deeper soil (10–60 cm) sulfur and nitrogen test results from 2012 Mallee trial sites, taken pre-sowing from each replicate (3 cores bulked X 3 replicates)

Site	pH (CaCl ₂)	Depth (cm)	S (KCI-40) (mg/kg)	Available S (kg/ha)	Available N (NO ₃ , NH ₄) (kg/ha)
Lameroo	7.8	0–10	2.9	3.48	
	8.1	10–60	2.2	13.2	38.7
Murrayville	7.3	0–10	1.9	2.28	
	8.4	10–60	2.3	13.8	42
Paruna	6.5	0–10	3.6	4.32	
	8.1	10–60	1.4	8.4	35.6
Karoonda	7.3	0–10	1.8	2.16	
	8.3	10–60	17	102	36.6

These results are supported by literature suggesting that 0–10 cm KCl-40 is not always an accurate measure of crop S supply, and that a total approach similar to deep soil-N testing maybe more informative. Testing for S can be done in conjunction with nitrate tests at a small additional cost.

Deficiency of S may not be as widespread in the Mallee as first thought but, rather, limited to certain paddocks as demonstrated by the Lameroo site (Table 8), where there was a response to combined N and S fertilisers. Concerned growers should conduct deep soil testing or tissue testing, or apply a test strip to diagnose potential S deficiency more accurately. Deficiency of S can be diagnosed in the field by general yellowing in the younger leaves, whereas the mobility of N within the plant means N deficiency is observed in the older leaves.

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Table 8: Fertiliser effects on early vigour (normalised difference vegetation index, GS30) and grain yield in Hindmarsh barley at Lameroo, Paruna, and Murrayville in 2012

n.s., Not significantly different at P = 0.05

Treatment	Growth at	GS30 (%	nil control)	Gra	ain yield (t/ha)		
(kg/ha of nutrient)	Lameroo	Paruna	Murrayville	Lameroo	Paruna	Murrayville	
Nil	100	100	100	2.13c	1.63	1.21	
Gypsum (20 kg S)	103	105	96	2.14c	1.65	1.21	
Urea (17.5 kg N)	123	125	116	2.70b	1.58	1.19	
Sulfate of ammonia (17.5 kg N, 20 kg S)	123	123	112	2.96a	1.69	1.14	
Urea (17.5 kg N) + gypsum (20 kg S)	122	119	114	2.68b	1.54	1.08	
I.s.d. $(P = 0.05)$	10.1	9.8	12.2	0.24	n.s.	n.s.	

Nitrogen responses in 2012

Overall, N was the key nutrient driving early growth responses at all sites (Table 8) in 2012, and therefore the N balance was more important than S balance. Only at Lameroo was there a significant grain response to N, and an additional response to combined N and S (Table 8). The responses to N still depended on the deep soil N levels and seasonal site conditions.

Timing and form of nitrogen and sulfur application

The trial at Karoonda included additional treatments examining the effect of timing of application of N and S. Timing or form of N or S did not significantly change the yield response to fertilisation (Table 9). This is consistent with many experiments in South Australia that have found no consistent difference in the response to different forms of N fertiliser when applied at the same rate and timing. All yield responses to fertilisation could be explained by an N response, and not an S response.

A similar response to N was achieved across all three application timings. This response is not uncommon in Mallee farming systems, because DAP or MAP will supply a proportion of the N requirement, and the ongoing crop demand for N can be assessed throughout the growing season to better match seasonal conditions (soil moisture) with N supply. In lower yielding environments (<2.5 t/ha), N applied at seeding or early in the vegetative stage has been generally found more effective than delaying N application to stem elongation. Nitrogen applied later in the growing season will tend to influence grain protein rather than yield. Trials suggests that 5-6 kg N per t grain per ha will increase grain protein levels by one percentage unit.

Table 9: Grain yield (t/ha), yield response (compared with nil fertilised control), and grain quality data of Hindmarsh barley from the Karoonda nutrition trial in 2012 n.s., Not significantly different at P = 0.05

Fertiliser treatment	Grain yield (t/ha)	Yield response (t/ha)	Protein (% dry basis)
Nil N fertilised control	0.80	0.00	11.8
Nil N + gypsum (20 kg S)	0.78	-0.02	11.1
Urea at sowing (17.5 kg N)	1.12	0.32	11.4
Urea +gypsum at sowing (17.5 kg N, 20 kg S)	1.24	0.44	11.7
Sulfate of ammonia at sowing (17.5 kg N, 20 kg S)	1.20	0.40	12.3
Sulfate of ammonia at 3-leaf (17.5 kg N, 20 kg S)	1.15	0.35	11.1
Sulfate of ammonia at GS22 (17.5 kg N, 20 kg S)	1.38	0.58	12.2
I.s.d. $(P = 0.05)$		0.26	1.7

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Conclusions

Nitrogen was the main nutrient driving growth in these trials (although not underestimating the importance of S). Responses to N were more common than responses to S in Mallee cereals; fertiliser expenditure may be better targeted towards correcting N deficiencies first. Development of S deficiencies will depend on fertiliser history, crop rotation, and product removal and these should be considered on a paddock-by-paddock basis within a long-term nutrition program. Sulfur deficiency can be recovered by in-crop application of sulfate of ammonia, or avoided with a longer term strategy using alternate sources of S (Table 10).

Table 10: Sulfur content of commonly used fertilisers

Fertiliser form	% Sulfur
Superphosphate	11
Sulfate of ammonia	24
Agricultural gypsum	16–18
Triple superphosphate (TSP)	1.5
Di-ammonium phosphate (DAP)	1.0

Nutrition responses are largely driven by seasonal and site conditions and so trials are ongoing. Nonetheless, the results highlight the importance of a balanced approach to nutrition and the need for soil sampling at depth in the Mallee for both S and N. 40

5.11 Phosphorus

Australian soils are characteristically low in P in their native state, with the exception of a few soils of basaltic origin and some alluvial soils. Agriculture can further deplete soil fertility, even in soils that are initially high in P.

Most of the P in soils is associated with organic matter. Even in mineral soils, 20-80% of the total P will be present as organic forms.

Adequate P is essential for the early growth of barley. Many Victorian soils are low in available P, and much of the crop requirement may need to be supplied through the application of fertilisers at sowing. Paddock history of P application and crop yields in conjunction with soil test results and economics of application will determine the rates required.

The rule of thumb is a requirement for 3 kg/ha of available P for each tonne of barley anticipated. The application is then adjusted in the light of soil test results. 41

In most cropping systems, the Colwell-P soil test is still the benchmark soil P test used in Australia. Critical values differ between soil types, and the values given in Table 2 above are expressed for the major soil types in south-eastern Australia.

Through the GRDC-funded Better Fertiliser Decisions for Crop Nutrition (BFDC) project, the results of >5000 Australian crop nutrition trials have been collated in a single database. Of these, >2200 trials are from south-eastern Australia.

The PBI could not be directly related to the critical soil test value using the BFDC Interrogator, although other published data indicate that critical Colwell-P increases with PBI. Note that most of the trials were conducted prior to the PBI test being available.

On highly calcareous soils (Calcarosols), the DGT-P soil test provides a better prediction of crop response to fertiliser than Colwell-P. 42

More information

GRDC Fact Sheets: **Phosphorus** management (Southern Region)

GRDC Update Papers: Phosphorus—are we going to hit the wall and how much P in 2015?

GRDC Update Papers: Subsoil manuring

BFDC Interrogator: Case study: phosphorus in wheat

- K Porker, R Wheeler (2013) Barley nutrition and agronomy—do we need sulphur and nitrogen? GRDC Update Papers, 15 August 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/08/Barley-nutrition-and-agronomy
- Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, http://agriculture.vic.gov.au/agriculture/grainsand-other-crops/crop-production/growing-wheat
- GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS





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More

GRDC Update Papers:

going to hit the wall and

Phosphorus—are we

how much P in 2015?

Subsoil manuring

GRDC Update Papers:

information



February 2016

5.11.1 Phosphorus deficiency

Description (Figures 13 and 14):

- 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. 43

Phosphorus deficiency is one of the most widespread of nutrient deficiencies. Phosphorus is an important component of many molecules in plant cells and is therefore important for growing tissue, where cells are actively dividing (e.g. during development of seedling roots, flowering and the formation of seed). Phosphorusdeficient plants are stunted and dark green with short, erect leaves and stout stems that often develop orange, red or purplish discoloration. Many soils in cereal-growing areas will respond to the application of phosphate fertilisers. 44





Figure 13: Adequate (left) and inadequate (right) phosphorus nutrition. (Photos: Nigel Wilhelm, SARDI) 45

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GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/ Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide

DAF Qld (2010) Other elements of crop nutrition—phosphorus. Department of Agriculture and Fisheries $\label{lem:constraint} \textbf{Queensland,} \ \underline{\textbf{http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-pastures/broadacre-field-crops/nutrition-pastures/broadacre-field-crops/nutrition-pastures/broadacre-field-crops/nutrition-pastures/broadacre-field-crops/nutrition-pastures/broadacre-field-crops-and-pastures/broadacre-field-crops-nutrition-pastures/broadacre-field-crop$ management/other-nutrition

GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/ Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide





Figure 14: Phosphorus deficiency on the right-hand side of the image. (Photo: Nigel Wilhelm, SARDI)

Similar symptoms

Nitrogen deficiency also has yellowing of the oldest leaves, but death of the yellow tissue occurs more rapidly 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.

During early development, the requirement for P is small (perhaps 1 kg P/ha), 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 that these young plants have adequate P is essential to determination of grain number (i.e. yield potential) and ensuring 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 P/ha. Only 1–2 kg will be taken up from the banded P fertiliser applied at planting (either in or below and 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 (Table 11).

The need for P fertiliser can be determined by using soil tests (0–10 and 10–30 cm) and/or test strips of fertiliser. 46

GRDC Fact Sheets: Soil testing for crop nutrition (Southern Region)

Know more. Grow more.

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More information

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



Table 11: Adequate soil phosphorus ranges (Colwell-P) for different soil types

Soil test reading	Soil type
20-30 mg/kg	Sand
25-35 mg/kg	Loam
30-40 mg/kg	Clay

5.11.3 Phosphorus availability

A key consideration for growers with regard to fertiliser management is how much P will be supplied by the stubble, and when this P will be available to plants during the growing season. 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.

Stubble type, size and placement, and moisture supply and amount, can all significantly influence the timing and amount of P released from stubbles to the soil. Recent research aims to improve identification of P forms in crop stubble and to understand how these forms influence P release and breakdown from stubble, thereby providing a better estimation of the contribution of stubble P to subsequent crop P uptake.

Phosphorus within the stubble can be released directly to soil as soluble P (where it can be used immediately by the crop or chemically fixed onto the soil) or can be absorbed by microorganisms and subsequently released back into the soil.

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. ⁴⁷

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 immobilisation of 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 12 shows the actual rate of fertiliser product required to apply various rates of P.

Table 12: Products used primarily to supply phosphorus

Product trade name	% P in	Required	rate of ap	plication o	of P (kg/ha	a)
	product	4	6	8	10	15
Mono-ammonium phosphate (MAP)	22	18	27	36	45	68
Di-ammonium phosphate (DAP)	20	20	30	40	50	75
CK 700® (8.3% P)	8.2	49	73	98	122	183
Granulock® Z (21.8% P)	20.5	20	24	39	49	73

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





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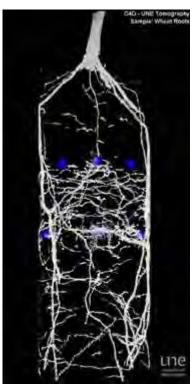


5.11.5 Phosphorus budgeting

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 a good season and good yields. How much P is required to achieve vigorous roots? To answer this question, we need to understand what is going on below the surface. How does a root system change the way that it grows in response to a high-concentration patch of P?

Figure 15 shows wheat roots responding to a band of P evenly distributed (between the blue dots) in a column \sim 0.3 m long and, by contrast, the root response to a granule of P placed at a similar depth in a similar pot.

Technologies such as computer-aided tomography allow researchers to answer questions about how root architecture changes in response to nutrition. The research can answer the question of how much P is required to create an architecture that allows for extensive exploration of soil volume. The aim is to find the lowest amount of P (and N) required to stimulate an efficient root system, which then frees the P resource to be spread more widely in the surface and subsoil, where those newly foraging and stimulated roots are best placed to find and exploit P in moist soil. ⁴⁸



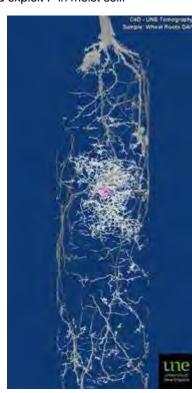


Figure 15: 3D Computer-aided tomographs of cereal root systems supplied with P in a diffuse band (left panel) or in a granule (right panel) after 30 days of growth.

5.11.6 Forms of phosphorus

Adequate P is not only an essential component of profitable and sustainable crop production but is also an increasing component of crop gross margins. The price of phosphatic fertilisers has increased, leading to interest in ways to improve P-fertiliseruse efficiency.

Use of liquid fertilisers has increased considerably, especially for the supply of N for crop production. Several products are available from a range of suppliers for use as starter fertiliser to provide P and micronutrients.

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⁴⁸ C Guppy, R Flavel (2011) Cereals seeking phosphorus: How much to spend on a first date? GRDC Update Papers, 6 Sept. 2011, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Cereals-seeking-phosphorus-How-much-to-spend-on-a-first-date





Research paper: Responsiveness of wheat (Triticum aestivum) to liquid and granular phosphorus fertilisers in southern Australian soils

Research in South Australia on highly calcareous soils (20-90% CaCO3) has shown benefits of using liquid fertilisers over the traditional granular forms. Researchers reported on dry matter responses to liquid and granular P fertilisers from soils collected from around Australia. The findings suggested that liquid P fertilisers also have potential applications in non-calcareous soils. 49

Trials in New South Wales found no difference between the types of fertiliser (liquid or granular) used with respect to plant growth or grain yield. It was concluded that when deciding whether to use liquid P fertilisers the additional cost of equipment needs to be taken into account. 50

If in doubt about the usefulness of any new products, use test strips on-farm and assess economic (as well as agronomic) effectiveness before adopting, or refer to local

Manures

Manure might seem cheaper by the tonne, but 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.

The cost of transporting and applying manure may be greater than that of traditional fertiliser, and should be added to budget comparisons. 51

5.12 Sulfur

Sulfur has historically been adequate for crop growth because it is supplied in superphosphate, and in rainfall in coastal areas, and some comes from gypsum. In the Southern Region, S-responsive soils are uncommon for cereals, but can be seen for

Sulfur inputs to cropping systems have declined with the use of low-S fertilisers: triple superphosphate, MAP and DAP. Sulfur is also subject to leaching and in wet seasons may move beyond the root-zone. Occurrence of S deficiency appears to be a complex interaction between the mineralisation of S from soil organic matter, seasonal conditions, crop species and plant availability of subsoil S. Similar to N, these factors affect the ability of the soil-S test to predict plant-available S. 52

5.12.1 Deficiency symptoms

- · Crops grow poorly, lack vigour and mature more slowly; reduced tillering, low grain yields and protein.
- Initially all leaves are pale green, but old leaves darker green (Figures 16 and 17).
- Youngest leaves turn pale yellow and eventually white; whole leaf is affected not just the area between the veins.
- Leaves generally do not die even when they have turned white.
- Old leaves remain green.

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TM McBeath et al. (2007) Predicting the response of wheat (Triticum aestivum L.) to liquid and granular phorphorus fertiliser n Australian soils. Australian Journal of Soil Research 45, 448-456, http://www.publish. csiro.au/paper/SR07044.htm

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GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS



In some varieties, margins and sheaths of old leaves become red or purple-red.

In severe deficiencies, the upper leaves are yellow to white in colour, with the lower leaves turning pale green. Tiller number will also be reduced.

Testing to 60 cm is suggested, with soil test levels <4 mg S/kg indicative of areas where it is necessary to undertake test strips of S application for growth responses. Consider applying ammonium sulfate into the soil at 75–100 kg/ha (15–24 kg S/ha) or broadcasting gypsum (calcium sulfate) at the rate of 500 kg/ha as test strips. 54

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. Fertilisers such as DAP and MAP are low in S. 55



Figure 16: Sulfur-deficiency symptoms on barley leaves (left and middle); adequate nutrition (right). (Photo: Hungry Crops, DAF Qld)

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GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide

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

⁵⁵ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide





Figure 17: Sulfur-deficient barley plant (left); plant with adequate nutrition (right). (Photo: Noel Grundon, DAF Qld)

5.13 Potassium

Potassium is important in vegetative growth and is essential for a number of metabolic processes, yet its precise functions are poorly understood. It does enhance N uptake and can increase protein content. It can also help to prevent lodging in cereals.

With the gradual decline in soil K levels from crop removal and historically low fertiliser application rates, some situations (particularly red soils) require K fertiliser applications. However, crops also vary in their response to improved soil K levels. Generally, winter cereal responses are low to moderate unless gross deficiencies occur. ⁵⁶

In the Southern Region, cropping soils are generally unresponsive to additions of K. However, as crops continue to mine K from soils, this may change. Potassium deficiency is more likely to occur on light soils and with high rainfall, especially where hay is cut and removed regularly.

Factors such as soil acidity, soil compaction and waterlogging will modify root growth and the ability of crops to extract subsoil K.

Potassium fertiliser inputs in Australian cropping systems have generally been low relative to other nutrients, with Reuter *et al.* (1997) estimating that, nationally, Australia had a negative K balance, with that balance strongly negative in broadacre cropping regions. ⁵⁷

5.13.1 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.

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DAF Qld (2102) Wheat—nutrition. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition

D Reuter D, D Duncombe-Wall, G Judson G (1997) Potassium balance in Australia's broadacre industries: a contemporary national and regional analysis. In Proceedings of the First Workshop on Potassium in Australian Agriculture. pp. 1–8. UWA Press.



- 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 (Figure 18). 58

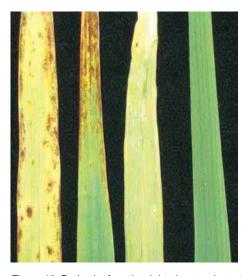


Figure 18: Barley leaf on the right shows adequate potassium nutrition; the others show inadequate K. (Photo: Noel Grundon, QDPI) 55

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 and/or grain will deplete K. 60

5.13.2 Critical levels and inputs

Potassium soil tests are reported as exchangeable K (meg/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, but in the interim, exchangeable K <0.3-0.4 cmol/ kg or 130-160 mg Colwell-K/kg would be considered low-marginal, and test strips worth a try.

Potassium is effectively immobile in the soil (like P), so profiles tend to stratify, with much higher levels in the top 10 cm and significant depletion in the 10-30 cm layer. Testing for soil K in both the 0-10 and 10-30 cm layers is advisable, with the deeper K testing essential when the topsoil is dry.

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 alternative to lower rates with each crop. However, K banded in the seed row can affect germination.



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GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/ Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide

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GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/ Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide





BFDC Interrogator: Case study: potassium in wheat

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.

Although soil K reserves are greatest in heavier alluvial and cracking clay soils, it is important to maintain adequate K soil levels by replacing that removed in harvested product as often as possible. Once soil K levels have been depleted in these soils, very heavy fertiliser K applications are required and this becomes prohibitively expensive. 61

5.14 Micronutrient deficiencies

Micronutrient deficiencies can be difficult to diagnose and treat. However, by knowing your soil type, considering crop requirements and the season, and supporting this knowledge with diagnostic tools and strategies, effective management is possible.

Key points:

- Micronutrient deficiencies are best determined by looking at the overall situation: region, soil type, season, crop, and past fertiliser management.
- Soil type is useful in determining the risk of micronutrient deficiencies.
- Soil testing can be a useful indicator.
- 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. 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 allow you to confirm whether the micronutrient was limiting. 62

5.14.1

Zinc is essential for protein shape 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. 63Zinc supplements can be applied with fertiliser as zinc oxide, chelated Zn or zinc sulfate. The products can also be used for foliar applications. Product efficacy varies with the time and placement of application. 64

Deficiency description (Figures 19 and 20):

- 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.

- GRDC (2013) Micronutrients. Crop Nutrition Fact Sheet GRDC, 4 November 2013, http://www.grdc.com.au/ GRDC-FS-CropNutrition-Micronutrients
- 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
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DAF Qld (2102) Wheat - nutrition. Department of Agriculture and Fisheries Queensland, http://www.daff.qld. gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition



- Affected areas may remain separate or join, with the death of the entire central leaf area; tip, base and margins remain green.
- With severe deficiency, yellow areas and grey-brown lesions develop on the leaf sheath; reduced tillering with no or little grain produced.
- 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. ⁶⁵





Figure 19: Zinc deficiency in barley. (Photos: DAFWA)



Figure 20: Zinc deficiency symptoms on barley leaves. (Photo: DAFWA)





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⁶⁵ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide



5.14.2 Copper

Copper is essential for chlorophyll formation and pollen production. Wheat and barley are more responsive to Cu than are lucerne and canola.

Deficiency is common in organic soils and 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. ⁶⁶

Deficiency symptoms in barley are depicted in Figures 21–24. 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:

- 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, plant heads may be more erect.
 Severely deficient plants have few immature heads on weak and dirty stems. 67

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). ⁶⁸





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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

MyCrop. Diagnosing copper deficiency in barley. Department of Agriculture and Food WA, https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-barley

⁶⁸ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide





Figure 21: Copper deficiency in barley: head sterility causes delayed maturity. (Photo: DAFWA)



Figure 22: Copper deficiency symptoms on barley leaves. (Photo: Hungry Crops, DAF Qld)



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Figure 23: Copper deficiency in barley: severely affected plants have no grain. (Photo: DAFWA)



Figure 24: Deformed barley heads indicating copper deficiency. (Photo: Nigel Wilhelm, SARDI)



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Alleviation

Copper can be applied as an additive to fertilisers, or as foliar spray as copper sulfate, copper oxychloride or chelated Cu. It also has a fungicidal effect.

Copper sulfate applied to the soil at 10–20 kg/ha prior to or at planting will last for a number of years. One foliar spraying at booting may still be necessary in dry years.

Alternatively, apply two foliar sprays of 1% copper sulfate/ha (1 kg copper sulfate to 100 L water/ha). Apply the first spray 3–5 weeks post-emergence and the second spray any time from when the ear begins to swell the stem of the plant to when the plant is in the boot stage. Foliar sprays have little residual value and they must be applied every year. ⁶⁹

5.14.3 Boron

Boron deficiency

Key points:

- Boron is essential for germination and sugar metabolism.
- Symptoms of deficiency include stem splitting and poor grain set.
- Liming can induce boron deficiency.
- Critical tissue levels are <2 mg/kg in the youngest mature leaf blade at mid–late tillering. Leaching can reduce tissue levels.
- Boron sources are borax, boric acid, Solubor®, ulexite and sodium pentaborate.
- · Even application is critical.

Description of deficiency:

- Stems are short and often fan-shaped; leaves are greyish-green.
- Dark brown, irregular spots occur on young leaves (Figure 25).
- Pale yellow areas in the middle of young leaves.
- Yellowing quickly moves towards the leaf tip and irregular, grey spots develop between the edge and mid-vein; spots often join, leaving grey dead tissue with vein unaffected.
- Eventually whole leaf tip dies turning grey-brown, with base of leaf remaining pale green.
- In severe deficiency, youngest leaves fail to develop or expand fully and sometimes die; leaves tear and tips die and turn grey.

Similar symptoms

Deficiency of Ca shows similar symptoms of youngest leaf damage but lacks grey lesions and the young leaf tip twists and dies. ⁷¹

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DAF QId (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

GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide

MyCrop. Diagnosing boron deficiency in barley. Department of Agriculture and Food WA, https://www.agric.wa.gov.au/mycrop/diagnosing-boron-deficiency-barley



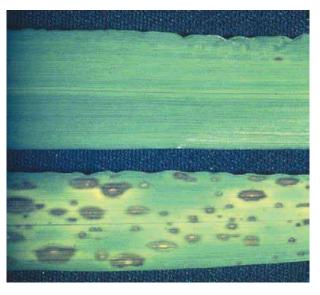


Figure 25: Symptoms of boron deficiency in barley (lower leaf). (Photo: Hungry Crops, DAF Qld)

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 oldest leaves first (Figure 26). Symptoms often do not appear in early vegetative growth.

Similar symptoms

Spot form of 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 boron-intolerant varieties. 72



Figure 26: Symptoms of boron toxicity on barley leaves: Hamelin((left), Mundah((right). (Photo: DAFWA)





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⁷² GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide



5.14.4 Iron

Key points:

- Iron is an essential component of chlorophyll and respiratory enzymes.
- Chlorosis of the youngest part of the plant is the most common symptom of deficiency.
- Deficiency is worst in high-pH and low-organic-matter soils, especially if there is a
 lot of free bicarbonate (of soil or irrigation water origin).
- Soil analysis is not able to provide critical values, and tissue samples can be easily contaminated with Fe from soil. Levels >70 mg/kg in tissue seem adequate.
- Foliar sprays are useful as iron sulfate or side dressings with iron chelates.

Description of deficiency:

- Plants are stunted with thin, spindly stems and pale green to yellow leaves (Figures 27 and 28).
- · Youngest leaves turn pale green.
- Leaves develop yellow (between the veins) and green (veins) stripes down the length of the leaf (interveinal chlorosis).
- In severe deficiency, yellow stripes may turn almost white, but do not die; veins become pale green to yellow; tillering reduced and young tillers die.
- · Old leaves remain pale green.

Similar symptoms

Deficiencies of N and S result in pale plants; *Barley yellow dwarf virus* causes yellow stripes.

Contributing factors

Contributing factors include highly calcareous soils and waterlogged conditions. 73



Figure 27: Iron deficiency on wheat leaves, showing prominent green veins (symptoms are similar in barley). (Photo: Hungry Crops, QDPI)



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⁷³ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide





Figure 28: Iron deficiency in wheat crop (symptoms are similar in barley). (Photo. Mark Seeliger, PIRSA)

5.14.5 Manganese

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 are considered deficient.
- Foliar Mn can be more efficient than soil-applied Mn, because the latter can result in Fe or phosphate precipitates. Chelated formulations are also available.

Description of deficiency:

- Deficiency often appears as patches of pale, floppy plants in an otherwise green, healthy crop.
- Pale green stripes usually develop on young leaves; blotches develop that may have a thin brown rim (Figure 29).
- Leaves are weak and tear easily.
- Tillering is greatly reduced with extensive leaf and tiller death (Figure 30). With extended deficiency, the plant may die.
- Surviving plants produce fewer and smaller heads.



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Figure 29: Manganese deficiency symptoms on barley leaf. (Photo: Nigel Wilhelm, SARDI)



Figure 30: Manganese deficiency in barley crop (left); adequate (right). (Photo: Nigel Wilhelm, SARDI)

Similar symptoms

Zinc deficiency causes patches of pale stunted plants but not 'floppy'.

Contributing factors

Manganese is low in many acid soils and is lost from free-draining soils (e.g. sandy soils). Highly calcareous sands, very infertile siliceous sands, alkaline peats, cold and wet conditions, and high rates of lime are contributing factors to Mn deficiency. Application of some herbicides makes the problem worse. ⁷⁴



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GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide



Manganese toxicity

Manganese toxicity symptoms include grey flecks or either yellow or brown spots developing on leaves (Figure 31).

Similar symptoms

The flecking symptom could be confused with insect damage, and the yellow spots could be confused with some leaf diseases or herbicide damage.

Contributing factors

Toxicity is likely to occur in acid soils (pHCaCl $_2$ <4.5) and in wet, poorly drained soils; these conditions make Mn more available for plant uptake. ⁷⁵



Figure 31: Manganese toxicity in barley (left and middle) compared with healthy leaf (right). (Photo: Hungry Crops, DAF Qld)

5.14.6 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.
- Very small quantities (50 g Mo/ha) applied with fertiliser are usually sufficient, usually in the form of molybdenum trioxide. Sodium or ammonium molybdate can be used as sprays.

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⁷⁵ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide

MyCrop. Diagnosing molybdenum deficiency in cereals. Department of Agriculture and Food WA, https://www.agric.wa.gov.au/mycrop/diagnosing-molybdenum-deficiency-cereals

Incitec Pivot. Molybdenum fact sheet. Fertfacts. Incitec Pivot, http://www.incitecpivotfertilisers.com.au/en/Agronomy/~/media/Files/IPF%20Migration/FertFacts/MolybdenumFS/MolybdenumFSV3IIPLLM15102009.





Figure 32: Wheat grown without (left) and with molybdenum (symptoms are similar in barley). (Photo: Snowball and Robson 1988)

Description of deficiency (Figure 32):

- 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 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 shrivelled grain, late tillering.

Contributing factors

Factors include acidic soils, moderate to high levels of available soil N, and soils high in iron and aluminium oxides. 78

5.14.7 Magnesium

Description of deficiency (Figure 33):

- Young crops have poor growth with pale yellow leaves.
- In more mature crops, plants are stunted with thin spindly stems and pale yellow foliage marked with necrotic lesions.
- 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.



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⁷⁸ GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide



Contributing factors

Applications of high rates of high-quality lime can contribute. Magnesium deficiency is rare in broadacre agricultural crops. 79



Figure 33: Magnesium deficiency symptoms in barley. (Photos: Noel Grundon, DAF Qld)



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GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, http://www.grdc.com.au/Resources/ Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide



SECTION 6

Weed control

Weeds cost Australian agriculture an estimated AU\$2.5–4.5 billion per annum. For winter cropping systems alone the cost is \$1.3 billion. Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry. ¹

For the Southern Region, the most important summer weeds based on estimated reduction in subsequent crop yield potential were: heliotrope, melons, fleabane, panic grass, caltrop, Lincoln weed and windmill grass.

Growers in the Southern Region were estimated to be incurring losses of \$23/ha from the impact of summer weeds on subsequent crop yields, with \$17/ha estimated to be spent on summer weed control of cropped land, on average. This suggests opportunities for profitable practice change.

Brome grass is now one of the most costly winter weeds across the Southern Region. Overall, growers are investing heavily in winter weed control and are managing to keep weed densities and the cost of yield losses relatively low compared with management costs (Table 1). ²

Table 1: Cost of residual weeds on yield loss in winter cereals for the Southern Region and its agro-ecological zones

Southern Region		SA Midnorth-Lower Yorke Eyre	
Ryegrass	\$34.1M	Ryegrass	\$19.6M
Brome grass	\$19.7M	Brome grass	\$7.6M
Wild oats	\$17.3M	Wild oats	\$1.5M
Wild radish	\$6.5M	Barley grass	\$439.2K
Wild mustard	\$3.2M	Wild mustard	\$332.3K
Amsinckia/yellow burr	\$1.9M	Cutleaf mignonette	\$292.5K
Wireweed	\$1.4M	Wild radish	\$281.5K
Barley grass	\$687.3K		
Skeleton weed	\$672.6K		
Doublegee	\$581.1K		
SA-Vic Bordertown - Wimn	nera	SA-Vic Mallee	
Wild oats	\$5.9M	Brome grass	\$6.7M
Brome grass	\$4.3M	Ryegrass	\$2.9M
Ryegrass	\$4.1M	Wild radish	\$1.9M
Wild mustard	\$1.6M	Amsinckia/yellow burr weed	\$1.9M
Prickly lettuce/whip thistle	\$526.3K	Wireweed	\$1.3M

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

More information

GRDC Update Papers: Hitting the right target

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GRDC (2015) Hitting the right target—what are our most costly weeds?. GRDC Update Papers, 10 February 2015, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Hitting-the-right-target





Agriculture Victoria: **Diagnostic services**

GRDC: Weed Webinars

GRDC: Weed ID. The **Ute Guide**

NHT: Introductory weed management manual

NSW DPI: WeedWise

Sydney Royal Botanic Gardens Herbarium: **PlantNET**

WA Herbarium: **FloraBase**

WEEDpak Weed ID guide

Weeds Australia: Weed identification tool

Weeds Society of WA: Western Weeds

Wild radish	\$470.4K	Wild mustard	\$589.8K
Lincoln weed	\$453.9K	Skeleton weed	\$474.7K
		Wild oats	\$430.8K

Weed control is essential if barley is to make full use of stored summer rainfall and winter rainfall, and to prevent weed seeds from contaminating the grain sample at harvest. Weed management should be planned well before planting and options considered such as chemical and non-chemical control. Paddock selection is also

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

Weed control is important, because weeds can:

- rob the soil of valuable stored moisture
- rob the soil of nutrients
- cause issues at sowing time, restricting access for planting rigs (especially vinetype weeds such as melons, caltrop or wireweed, which wrap around tines)
- cause problems at harvest
- increase moisture levels of the grain sample (green weeds)
- contaminate the sample
- prevent some crops being grown where in-crop herbicide options are limited, i.e. broadleaf crops
- be toxic to stock
- carry disease
- host insects

6.1 Integrated weed management (IWM)

Rapid expansion of herbicide resistance and the lack of new modes of action (MOA) require that 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 the future sustainability and profitability of cropping systems.

The last significant new herbicide MOA released in Australia was Group H chemistry, launched in Australia in 2001. Prior to that, the most recent new MOA was Group B chemistry, when chlorsulfuron was commercialised in Australia in 1982.

Successful weed management requires a paddock-by-paddock approach. Weeds present and in the weed seed-bank, soil types in relation to herbicide used, 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 still work becomes critical.



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



The following 5-point plan will assist in developing a management plan for each paddock:

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

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 higher 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 in which a herbicide MOA has been used 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 the 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 2). Thus, in the above example, a 'watching brief' would be in place for trifluralin and other Group D MOA herbicides.

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

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





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

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



Table 2: 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

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

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: <a href="https://linear.com/l

6.1.4 Fine-tune your list of options

Which are your preferred options to add to current weed-management tactics to add diversity and help drive down the weed seedbank? ⁸

6.1.5 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. 9





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

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

⁸ GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub

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





NSW DPI: Weed management in winter crops

NSW DPI: Weed management in summer



GRDC Update Papers

Biology and management of summer weeds

Brome and barley grass management in cropping systems of southern <u>Australia</u>

Fleabane ecology and control in cropping systems of southern Australia

Fodder rotations with cropping to manage weeds

Hardseeded annual legumes

Herbicide efficacy in no-till farming systems in southern NSW

Herbicides for control of clethodin-resistant annual ryegrass

<u>Hitting the right target</u> what are our most costly weeds?

Impact of crop residues on summer fallow weeds

Managing annual ryegrass in cropping systems - pre and post emergent herbicide trial Barellan 2013

New herbicide challenges and solutions

New technology for improved herbicide use efficiency

NGA chickpea herbicide trials 2015

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 alternative strategies and tactics for ryegrass management to be compared for profit over time and for impact on weed numbers. The software's underlying model integrates biological, agronomic and economic considerations in a dynamic and user-friendly framework, 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 with the crop. 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. 1

Weed Seed Wizard

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

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

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

A free download is available from: https://www.agric.wa.gov.au/weed-seed-wizard-0.2

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



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



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GRDC Update **Papers**

Optimising the impact of glyphosate

Seeding systems and pre-emergence herbicides

Summer weeds reduce moisture and nitrogen

Using crop competition for weed control in barley and wheat

Why the obsession with the ryegrass seed bank?

6.2 Agronomy

- Know your weed species. Ask your local adviser or service provider or use the Sydney Botanic Gardens Plant ID and Diagnostic Services, which is free in most cases.
- Conduct in-crop weed audits prior to harvest to know which weeds will be problematic the following year.
- Ensure barley seed is kept from a clean paddock (Figure 1).
- Have a crop-rotation plan that considers not just crop type being grown but also what weed control options this crop system may offer.



Figure 1: Ensure barley seed is kept from a clean paddock. (Photo: A. Mostead)

Crop choice and sequence 6.2.1

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 and help to 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. 10

For a list of crop choice options to aid weed management, go to the tables within IWM Section 3: Agronomy.

Some key issues:

Select crop sequences and varieties to deal with the significant pathogens and nematode issues for each paddock.



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



- Weeds are alternative hosts to some crop pathogens. 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.

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.

Leaf area index at the end of tillering in wheat is highly correlated with the crop's ability to compete with weeds.

Canopy development is influenced by:

- crop type and variety
- row spacing, sowing rate and sowing depth (Figure 2)
- crop nutrition
- · foliar and root diseases
- nematodes
- levels of beneficial soil microbes such as mycorrhizae
- environmental conditions including soil properties and rainfall
- light interception and crop row orientation

it is suited to the growing conditions.

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 the above factors.

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 advisors should check its performance under weed pressure to ensure that

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



GRDC Update Papers:
Using crop competition
for weed control in
barley and wheat

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

S Goss, R Wheeler (2015) Using crop competition for wed 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



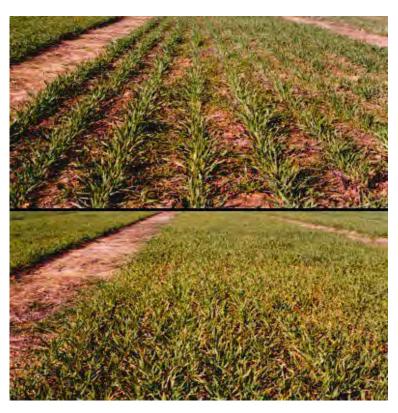


Figure 2: Difference in crop competition between low (top) and high (bottom) seeding rates. (Photo: D. Minkey)

Key issues:

- · Good agronomy generally means a competitive crop.
- A competitive crop greatly improves weed control by reducing weed biomass and seedset (Figure 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.
- · Take care to 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.



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Figure 3: Common sowthistle growing in-fallow (no competition) v. growing in-crop (wheat and barley), Condamine, Qld. There was no in-crop herbicide applied to control the weed. The lack of sowthistle in-crop is entirely due to crop competition. The season had a relatively dry start, so the crop established before the weeds. (Photo: M. Widderick)

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 (IT) wheat (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 able to be used in these crops.

With the ease and high levels of weed kill often experienced with glyphosate use in Roundup Ready® (RR) crops, the frequency of use of other control tactics has declined. Diversity in weed-management tactics has decreased and selection pressure for the development of resistance to glyphosate has increased. In an attempt to offset this, many of the stewardship packages associated with herbicide-tolerance technologies require the use of alternative technologies in situations where weed density or the evaluated risk of resistance to that herbicide is high.

Specific herbicide-tolerance crop-technology stewardship programs are a source of more detailed information. For example, the 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 <u>CropLife Australia Limited</u> website.

Some requirements of the stewardship packages include:

- Use technologies and weed management strategies that are appropriate to the weed spectrum and pressure.
- Adhere to all herbicide label directions.
- Maintain good paddock management records.
- Use agronomic practices to minimise outcrossing with other crops.



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GRDC: Summer fallow weed management manual

Integrated Weed Management Section 3: Agronomy



Break crop benefits. Western Region

Group A herbicides in fallow

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Crop placement and row spacing. Southern Region

Summer fallow spraying. Northern, Southern and Western Regions

Time of sowing. Northern, Southern and Western Regions

Weed control in wheel tracks. Northern, Southern and Western Regions

GRDC Update Papers

Biology and management of summer weeds

Compete with weeds give your crop heaven and your weeds hell

Crop sequencing—what are the key issues to making profitable and sustainable crop sequencing decisions?

Impact of crop residues on summer fallow <u>weeds</u>

Landscape and weed influence on pest and beneficial insect populations

6.2.4 Improving pasture competition

Pastures represent an important component of many rotations and provide a valuable opportunity to manage weed problems by using tactics not available in cropping situations. These include grazing, mechanical manipulation and non-selective herbicides. Dense stands of well-adapted pasture species compete against weeds, reducing weed numbers and weed seedset. Competitive pastures greatly improve the effectiveness of other tactics to manage weeds in the pasture phase.

Some weeds such as fleabane have few viable management options in pastures, and this is where blowouts often occur.

Identification and management notes on a large range of weeds of pasture are available at NSW WeedWise.

6.2.5 **Fallow phase**

Fallows are defined as the period between two crops, or between a crop and a defined pasture phase. Fallows are used to store and conserve soil moisture and nitrogen (N) for the next crop, reduce the weed seedbank and stop weed growth that could impede the sowing operation.

Benefits:

- A fallow period on its own, or in sequence with a number of crops, can be highly effective in reducing the weed seedbank.
- A fallow period can incorporate several tactics to reduce weed seedbanks.
- A double-knock of glyphosate followed by paraquat can give high levels of weed control and can assist control of some hard-to-kill or glyphosate-resistant survivors.
- If planned, it is sometimes possible to use other herbicide MOA groups with residual activity (Groups C, B, I or K) in fallow.
- In a fallow, it is easier to spot escapes and take action to stop seedset than in a crop.

Key factors for success:

- Control weeds of fallows when they are small.
- Try to include a range of tactics that include different MOA groups, paraquat and residual herbicides to avoid over-reliance on glyphosate alone. Occasional tillage should also be considered when there is a drying seedbed.

For Southern and Western Regions, further information can be found in the Summer Fallow Weed Management Manual. 13

6.2.6 Controlled traffic for optimal herbicide application

Controlled traffic (or 'tramlining') refers to a cropping system designed to limit soil damage by confining all wheel traffic to permanent lanes for all paddock operations, including seeding, harvesting and all spraying (Figure 4).

Some form of traffic lane will reduce compaction between the tramlines, resulting in increased health of the crop through improved soil characteristics, thus improving the competitive ability of the crop. This form of precision agriculture results in;

- more efficient use of pesticide application through reduced overlaps
- ability to treat weeds in the inter-row more easily
- easier management of weed seeds at harvest

Accurately spaced tramlines provide guidance and a firmer pathway for more timely and accurate application of herbicide, which in turn improves weed control and reduces input costs by 5-10%.

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



GRDC Update **Papers**

Non-herbicide tactics to help suppress weed growth

Progress in developing weed competitive wheat

Seeding systems and pre-emergence herbicides

Summer weeds reduce moisture and nitrogen

Using crop competition for weed control in barley and wheat



AGT: Weed tolerance and suppression in wheat

AWC research paper: Canola competition for weed suppression

AWC research paper: Competitive effects of sorghum cultivars and densities on weed suppression

AWC research paper: Cover cropping as a weed management tool in southern Australian farming systems

AWC research paper: Managing herbicide resistance in Southern Australian farming systems using Roundup Ready® canola

AWC research paper: Weed suppression by crop competition in three crop species in Western <u>Australia</u>

GIWA research paper: Aim for the narrowest possible row spacing WA

WeedSmart You Tube video: Diverting weed seed onto permanent **tramlines**

In wide-row controlled-traffic systems, inter-row-shielded and band spraying as well as inter-row tillage may be options. Precision-guidance technology potentially makes such options more practical, but there are very few registrations allowing use of herbicides in this manner. 14



Figure 4: Controlled traffic cropping allows more options for weed control and management. (Photo: A. Mostead)

Key weeds in Australia's cropping systems 6.3

Annual ryegrass (Lolium rigidum)

Barley grass (Hordeum spp.)

Barnyard grasses (Echinochloa spp.)

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)

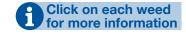
Liverseed grass (Urochloa panicoides)

Muskweed (Myagrum perfoliatum)

Paradoxa grass (Phalaris paradoxa)

Silver grass (Vulpia spp.)

Sweet summer grass (Brachiaria eruciformis)





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



Turnip weed (Rapistrum rugosum)

Wild oats (Avena fatua and A. Iudoviciana)

Wild radish (Raphanus raphanistrum)

Windmill grass (Chloris truncata)

Wireweed (Polygonum aviculare and P. arenastrum) 15

6.4 Stopping weed seedset

6.4.1 Seedset control tactics

Seedset control tactics include spray-topping with selective and non-selective herbicides, wick wiping, windrowing and crop desiccation, and 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.

Seedset control tactics are particularly effective in low-level weed populations.

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 weedmanagement 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 types of tactic. ¹⁶

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 of certain weeds. 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 (see spray-topping in <a href="https://links.com/links.co

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 (see below: *6.6 Herbicide resistance*).

Wild radish seeds can be viable once an embryo is visibly formed in the pod. This can occur within 21 days of flowering. 17

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GRDC (2014) Section 8. Profile of common weeds of cropping. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/lWMhub/Section-8-Profiles-of-common-weeds-of-cropping

¹⁶ GRDC (2014) Section 5. Stopping weed seedset. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-5-Stopping-weed-seed-set

¹⁷ GRDC (2014) Section 5. Stopping weed seedset. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-5-Stopping-weed-seed-set

information

IWM Section 4. Tactics

C-Dax Eliminator weed

INLAND: Eliminator

weed wiper

wiper



February 2016

6.4.3 Weed wiping

Wick wiping, blanket wiping, carpet wiping and rope wicking are all forms of weed-wiping technology that are aimed at reducing weed seedset by using a range of devices to wipe low volumes of concentrated herbicide onto weeds that have emerged above the crop (Figure 5). Weed wiping is selective because of the application method rather than the herbicide used.

Weeds must be at least 30 cm taller than the crop. Care is needed to ensure that excess herbicide does not drip on to the crop and cause damage.

Weed wiping is most effective when the target weed is most vulnerable. For *Brassica* weeds, wiping at flowering to early podfill stages will achieve the greatest reduction in seedset. The level of weed control decreases after the weed reaches mid podfill.

Weed wipers have developed significantly and include models with multiple ropes, carpets, sponges, revolving cylinders and pressurised supply, which make them significantly more effective. ¹⁸



Figure 5: Blanket wipers use a sheet (blanket) moistened with herbicide to wipe the weeds above the crop. (Photo: A. Storrie)

6.4.4 Crop desiccation and windrowing

Crop desiccation with a non-selective herbicide and windrowing (also called 'swathing') are harvest aids; the growth stage of any weeds present is not a consideration. However, 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; and
- 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).





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¹⁸ GRDC (2014) Section 5. Stopping weed seedset. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-5-Stopping-weed-seed-set



Any weed regrowth must be controlled to minimise seed production.

Harvest withholding periods must be known before using herbicides for crop desiccation. ¹⁹

See IWM Section 4: Tactics.

6.4.5 Manuring, mulching and hay freezing

Sacrificing of 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.

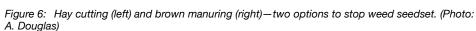
Green manuring incorporates green plant residue into the soil with a cultivation implement, and brown manuring uses non-selective herbicides (Figure 6).

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. 20







IWM Section 4: Tactics

GRDC Fact Sheets:

Manuring of pulse crops

6.5 Pasture seedset control

6.5.1 Pasture spray-topping

Pasture spray-topping should be used for 2 years before growing a cereal crop, to reduce grass numbers and potential for crop root disease. It is not a substitute for long fallow.

Pasture spray-topping involves application of a non-selective herbicide at flowering of the weeds, followed by heavy grazing, to reduce weed seedset.

Pasture spray-topping is possible because annual grasses become more sensitive to non-selective knockdown herbicides during flowering. This increased sensitivity allows A

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GRDC (2014) Section 5. Stopping weed seedset. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/lWMhub/Section-5-Stopping-weed-seed-set

GRDC (2014) Section 5. Stopping weed seedset. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-5-Stopping-weed-seed-set



lower rates of herbicide to be used to prevent the formation of viable grass seeds, with limited effect on desirable pasture species.

Usually, only one species can be targeted with pasture spray-topping because of differences in the time of flowering between species. Seed production of annual ryegrass can be reduced by up to 90%, whereas barley grass (*Hordeum* spp.) is reduced by ~65% owing to its extended head emergence.

Although pasture spray-topping is targeting a different plant growth stage (i.e. flowering and seedset), a plant already resistant to that herbicide MOA will exhibit little or no effect. ²¹

See IWM Section 4: Tactics.

6.5.2 Silage and hay

Silage and haymaking can be used to manage weeds by:

- reducing the quantity of viable seed set by target weeds, and
- removing viable weed seeds so that they are not added to the soil seedbank.

Silage and haymaking can reduce weed seed numbers by >95% if conducted before weed seedset, and any regrowth is controlled by herbicide or heavy grazing. ²²

See IWM Section 4: Tactics.

6.5.3 Grazing to manage weeds actively

Grazing management can aid weed management by:

- · reducing weed seedset
- · reducing weed competition
- encouraging domination by desirable species

The impact is intensified when the timing of grazing coincides with the vulnerable stages of the weed life cycle. This can be achieved through:

- timing grazing pressure to manipulate pasture composition
- grazing being used in conjunction with herbicides (spray-grazing) to manage weeds effectively (e.g. winter application of sublethal rate of MCPA on broadleaf weeds in clover-based pasture)
- exploiting differences in species acceptability to sheep, which can reduce weed numbers (e.g. grasses are more palatable in autumn)

Problems encountered by farmers when using grazing to manage weeds include:

- grazing pressure often not high enough to prevent selective grazing (Figure 7)
- · incorrect timing of practices to obtain the desired level of weed control
- risk of livestock importing weeds or transporting them to other paddocks ²³

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GRDC (2014) Section 5. Stopping weed seedset. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-5-Stopping-weed-seed-set

²² GRDC (2014) Section 5. Stopping weed seedset. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-5-Stopping-weed-seed-set

²³ GRDC (2014) Section 5. Stopping weed seedset. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-5-Stopping-weed-seed-set





IWM Section 4: Tactics

GRDC Fact Sheets: Manuring of pulse crops

GRDC Update Papers: Fodder rotations with cropping to manage weeds

GRDC Update Papers: Integrated weed management - Crop topping in wheat

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



Figure 7: Sheep are effective weed managers if stocking rates can be kept high enough. (Photo: A. Storrie)

6.6 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 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. ²⁴

6.6.1 **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

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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-papers/2014/03/The-



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Ten ways to weed out herbicide resistance

- 1. Act now to stop weeds from setting seed:
 - » 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 1-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.
- 2. Capture weed seeds at harvest. Options to consider are:
 - » Tow a chaff cart behind the header.
 - » Check out the new Harrington Seed Destructor.
 - » Create and burn narrow windrows.
 - » Produce hay where suitable.
 - » Funnel seed onto tramlines in controlled traffic farming systems.
 - » Use crop-topping where suitable (Southern and Western Regions).
 - » Use a green or brown manure crop to achieve 100% weed control and build soil N levels.
- 3. Rotate crops and herbicide MOAs:
 - » Look for opportunities within crop rotations for weed control.
 - » 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.
- 5. Aim for 100% weed control and monitor every spray event:
 - » Stop resistant weeds from returning into the farming system.
 - » 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.
- 6. Do not automatically reach for glyphosate:
 - » Use a diversified approach to weed management.
 - » Consider post-emergent herbicides where suitable.
 - » Consider strategic tillage.
- 7. Never cut the on-label herbicide rate and carefully manage spray drift and residues:
 - » 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®.





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Agronomy Australia:

The extent of herbicide

resistance in Tasmanian

wild radish populations

information



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- 8. 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.
- 9. 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.nga.org.au.
- Employ crop competitiveness to combat weeds:
 - » Consider narrow row spacing and seeding rates.
 - » Consider twin-row seeding points.
 - » Use high-density pastures as a rotation option.
 - » Consider brown manure crops.
 - » Rethink bare fallows. 25

6.7 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, etc., 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 Western Australian 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



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



few centimetres of soil. Burying some types of weed seeds can increase seedbank dormancy and slow the rate at which the seedbank is depleted. ²⁶

6.7.1 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 (Figure 8). Burning over summer poses an unduly high fire hazard and is illegal in most regions. 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 from cereal, canola or pulse crops is concentrated with weed seed in a narrow windrow and then burnt. ²⁷



Figure 8: Chaff dumps can be burnt in autumn killing a high proportion of seeds present. (Photo: A. Storrie)

6.7.2 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 (Figure 9). This predation of seed contributes to 'natural mortality' and partly explains why less seed germinates than is produced.

Understanding the role that insects play in removing weed seeds could help the development of farming systems that encourage greater removal of seeds from the seedbank. In New South Wales, seed theft by ants has commonly caused failure of pastures, and data from Western Australia show that ants can remove 60% or more of annual ryegrass in no-till systems, where weed seed is on the soil surface and

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GRDC (2014) Section 3. Managing the weed seedbank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-3-Managing-the-weed-seedbank

GRDC (2014) Section 3. Managing the weed seedbank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-3-Managing-the-weed-seedbank



accessible. Therefore, weed seedbanks could be also decreased by encouraging ant predation. ²⁸



Figure 9: Grass seeds collected by ants. (Photo: A. Storrie)

6.7.3 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. At a shallow depth of 1–3 cm, the seed has better contact with moist soil and it is protected from drying. Because weeds that germinate after an autumn tickle can be controlled, such a process will ultimately deplete weed seed reserves.

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. ²⁹

6.7.4 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 (Figure 10).

This tactic is most commonly employed for paddocks that 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.

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²⁸ GRDC (2014) Section 3. Managing the weed seedbank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-3-Managing-the-weed-seedbank

²⁹ GRDC (2014) Section 3. Managing the weed seedbank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-3-Managing-the-weed-seedbank



Choosing a crop or cultivar with a later optimum sowing time can reduce yield impact of a later sowing date. 30



Figure 10: Delayed sowing allows use of knockdown herbicides or cultivation to control small weeds prior to sowing, reducing the pressure on selective in-crop herbicides. (Photo: D. Holding)

6.8 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 interrow 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.' (Gill and Holmes 1997) 31

6.8.1 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. ³² Planned cultivation can also be used as a non-herbicide component of a double-knock system (see <a href="https://www.lwm.numer.com/lwm.nu

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³⁰ GRDC (2014) Section 3. Managing the weed seedbank. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-3-Managing-the-weed-seedbank

³¹ GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-4-Managing-weed-seedlings

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





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.
- 3. 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.
- 5. 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)
- 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.
- It speeds breakdown of stubble and reduces protection from water and wind erosion
- In the weeks prior to sowing, it 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.



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Tillage works best in dry or drying soil environments. Weeds are easier to kill when small with smaller root systems. Larger plants may need a more aggressive implement and/or multiple passes. ³³

6.8.2 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 preemergent chemistries.

Hence, we need to look after what is available for as long as possible. 34

Further information on registered chemicals can be obtained from <u>APVMA</u> and <u>CropLife Australia</u>, and <u>Regional weed control references</u>.

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. They are also used in the crop, especially glyphosate in RR crops.

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

- controlling weeds before sowing (see <u>delayed sowing</u> and <u>agronomy</u> in IWM Section 3)
- herbicide-tolerant crops (<u>agronomy</u>)
- 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 <u>tactic 3.2</u>)
- brown manuring and hay freezing (see tactic 3.4)

Since its release in the late 1970s, glyphosate has become the most widely used herbicide in the world. Prior to this, paraquat was more commonly used. Developed to deal with capeweed in southern Australian farming systems, SPRAY.SEED® (paraquat + diquat) also improved the control of *Erodium* spp., capeweed (*Arctotheca calendula*) and black bindweed (*Fallopia convolvulus*) over paraquat used alone.

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 <u>Australian Glyphosate Sustainability Working Group</u> provides up-to-date information on glyphosate and paraguat resistance.



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

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

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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 wheat belt 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, proximity to adjoining crops are critical issues. ³⁵

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/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, the benefit of double-knock as a delaying strategy for the onset of resistance to glyphosate is greatly diminished. ³⁶

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 grass 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.)

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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



Weeds that are naturally tolerant of glyphosate:

• feathertop Rhodes grass (Chloris virgata)

Fleabane can be effectively controlled in the early rosette stage by double knockdown where paraquat alone or in-mix with diquat is applied 5–7 days after glyphosate, mixed with a suitably efficacious Group I herbicide.

Note that there are residual/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 and 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 1–2 weeks are beneficial, but delaying too long can lead to regrowth of weeds and poorer results.

Apply the first herbicide when the weeds are most likely to be killed (i.e. 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.

Be aware that use of double-knock strategy on a percentage of land each year will add logistical stress to spray operations. This needs to be planned for. ³⁷

Pre-emergent herbicides

Pre-emergent herbicides control weeds at the early stages of the life cycle, between radical (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. Preemergent 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.



GRDC: Summer fallow weed management

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



Less soluble herbicides such as simazine need to be mixed with the topsoil for best results. The more mobile herbicides such as sulfonylureas and imidazolinones may not need mechanical incorporation, because they move into the topsoil with water (rain or irrigation). 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 herbicide, environmental conditions and soil type.

The following influence the fate of herbicides in the soil (Table 3):

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



Table 3: 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 4). 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

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establishment process, the level of soil displacement over the crop row, follow-up rainfall and the physical nature of the seed furrow. $^{\rm 38}$

Table 4: 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 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 preemergent activity on subsequent weed germinations. This is particularly the case with some Group B, C, F and I herbicides. Group A products have sufficient residual activity that they may affect cereal crops if sown too soon after use.

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





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Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-4-Managing-weed-seedlings



- 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 and 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).

Good crop competition improves the efficacy of post-emergent herbicides. Barley was shown to be more competitive than wheat against black bindweed (*Fallopia convolvulus*) and turnip weed (*Rapistrum rugosum*), and higher crop populations improve the effectiveness of herbicides against these species (Figure 11).

In a study on the effect of crop type and herbicide rate on seedset of paradoxa grass, barley was more competitive than wheat at all rates of herbicide (Figure 12).

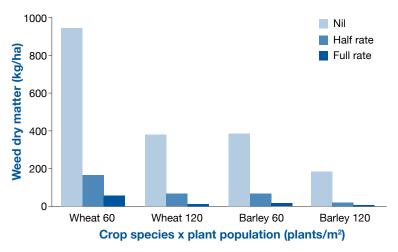


Figure 11: Effect of wheat and barley population and herbicide rate on the dry matter production of turnip weed and black bindweed measured at crop anthesis. (Source: Marley and Robinson 1990)

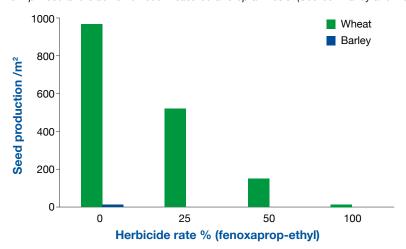


Figure 12: Effect of crop type and herbicide rate on paradoxa grass seed production. (Source: Walker et al. 1998)





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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 $<\!28^{\circ}\text{C}.$

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. For more detailed information on adjuvants, see the GRDC publication Adjuvants—oils, surfactants and other additives for farm chemicals.

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.

To drive the weed seedbank down over time, use later season seedbank management tactics in association with early post-emergent tactics (Table 5). Seedbank capture and management tactics work similarly to help drive the weed seedbank down.

Table 5: Effect of annual applications of different herbicide treatments on wild oat seedbank numbers after 5 years (Cook 1998)

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

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 ³⁹



Tactic 2.4 of IWM
Section 4: Tactics

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

When weed numbers are low or when still contained in patches, hand-weeding, spotspraying and other methods, including selective crop destruction, can be used to stop weed seedset and seedbank replenishment.





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³⁹ GRDC (2014) Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-4-Managing-weed-seedlings

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February 2016



AWC: Inter- and intra-row herbicide application strategies for the control of annual ryegrass in wide-row faba beans

AWC: Pyroxsulam for broad-spectrum weed control in wheat

CSIRO: Overview— Biological control of weeds

GIWA: Natural and environmentally friendly way of managing weeds without herbicides

GRDC: Adjuvants-Oils, surfactants and other additives for farm chemicals

GRDC: Regional weed control references

GRDC: Summer fallow weed management

GRDC Ground Cover: Advice at hand for fallow grass-weed control

IWM Section 4: Tactics

QAAFI: Double knock for controlling flaxleaf fleabane

Syngenta: SPRAY. SEED®

Weeds Australia: Target species for biological control



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

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

Pre-emergent herbicides (Northern, Southern and Western Regions)

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's 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 diary to check for later germinations. 40

6.8.4 Weed-detector sprays

Weed detector sprayers are used for the control of scattered weeds in crop fallows. Weed-detector-activated sprayers detect the presence of weeds using infrared reflectance units linked to a single nozzle. When a weed is detected, a solenoid turns on an individual nozzle and the weed is sprayed.

This technology is in use in the Southern Region, where it is reducing the volume of herbicide used in fallow per hectare by 80-95% depending on the density of the fallow weeds and the sensitivity settings of the sprayer.

This technology allows the use a range of herbicide MOAs and/or higher than usual rates while remaining economical.

A national APVMA minor use for the WeedSeeker® Permit (PER11163) allows several different MOAs to be used in fallows (valid until February 2019). Go to the APVMA site and enter the permit number.

Some added benefits and issues of this technology include:

- Drift risk is lower because coarse droplets are used and only a low percentage of the paddock is sprayed.
- Infrared signal enables use at night. Group L herbicides are often used as the second spray in double-knock programs and they tend to be more effective when sprayed late afternoon, in the evening or under cloudy conditions. A disadvantage of night spraying is a greatly elevated risk of inversion drift conditions.
- Weeds in wheat stubble should be higher than ~ 5 cm for reliable detection.
- Maintaining correct boom height, staying within design travel speeds and avoiding spraying in strong winds are essential for reliable performance. 41

Biological control 6.8.5

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, reduce weed vigour and

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

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

Spray equipment (Northern, Southern and Western Regions)

Spray height control (Northern, Southern and Western Regions)

Spray water quality (Northern, Southern and Western Regions)

Strategic tillage (Northern and Southern Regions)

Summer fallow spraying (Northern, Southern and Western Regions)

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

GRDC Update Papers

Achieving good preemergent spray results

Getting the right mix

Hardseeded annual <u>legumes</u>

Herbicide efficacy in no-till farming systems in southern NSW

Herbicide management in the summer fallow

Herbicides for control of clethodim-resistant annual ryegrass

Hitting the right target what are our most costly weeds?

New technology for improved herbicide use efficiency

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. 42

Harvest weed-seed control 6.9

Controlling weed seeds at harvest is emerging as the key to managing the increasing levels of herbicide resistance, which are putting Australia's no-till farming system at risk.

For information on harvest weed-seed control and its application for the southern grains region, see GrowNotes Barley South Section 12. Harvest.

6.10 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 is 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. 43

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.

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. 44

6.11 Herbicides explained

Residual v. non-residual

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

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall and irrigation, temperature and the herbicide's characteristics.

Persistence of herbicides will affect the enterprise's sequence (a rotation of crops, e.g. wheat-barley-chickpeas-canola-wheat).

Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and they are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

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GRDC Update **Papers**

NGA chickpea herbicide trials 2014

Pre-emergent herbicides interactions

Protecting glyphosate in summer fallows—mixes with pre-emergent herbicides and double knocking trials

Seeding systems and pre-emergence

The strategic use of tillage in conservation



Advances in weed application in summer

management: Stubble and soil binding of preemergent herbicides for annual ryegrass control in winter crops

Crop competition for weed management narrow row spacings

Double knock experience

Double knock knock strategies for resistant weed

Double knock applications—target weed species and

GCTV10: Double knock timing

never till?

6.11.2 Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, whereas pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. 45

and seeding system 6.12 Pre-emergent herbicides

The important factors in getting pre-emergent herbicide to work effectively while minimising crop damage are to understand:

- the position of the weed seeds in the soil
- the soil type (particularly amount of organic matter and crop residue on the surface)
- the solubility of the herbicide
- the herbicide's ability to be bound by the soil 46

Choice of herbicides for weed control in cereals will depend on the specific weed species present in the paddock and the crop being grown. Consult your agronomist to discuss specific strategies.

Pre-emergent herbicides control weeds at the early stages of the life cycle, between radicle (root shoot) emergence from the seed and seedling leaf emergence through the soil. Of the 14 herbicide MOA groups, eight are classed as having pre-emergent activity.

Pre-emergent herbicides may also have post-emergent activity through leaf absorption and they can be applied to newly emerging weeds. For example, metsulfuron methyl is registered for control of emerged weeds but it gives residual control typical of many pre-emergent herbicides.

Many herbicide treatments are solely applied pre-emergent (e.g. trifluralin).

6.12.1 **Benefits**

The residual activity of a pre-emergent herbicide controls the first few flushes of germinating weeds (cohorts) when the crop or pasture is too small to compete. The earliest emerged weeds are the most competitive. Therefore, pre-emergent herbicides are ideal tools to prevent yield losses from these early-season weeds.

The residual activity gives control of a number of cohorts, not just those germinating around the time of application.

Ideally, pre-emergent herbicides should be applied just prior to, or just after, sowing the crop or pasture. This maximises the length of time that the crop will be protected by the herbicide during establishment.

6.12.2 **Practicalities**

Planning is needed for the use of pre-emergent herbicides to be an effective tactic.

There are four main factors to consider when using pre-emergent herbicides.

1. Weed species and density. When deciding to use a pre-emergent herbicide, it is important to have a good understanding of the expected weed spectrum. Use paddock history and observations of weed species and densities from at least 12 months prior to application. Correct identification of the weed species present is vital. Pre-emergent herbicides are particularly beneficial if high weed densities are expected. Post-emergent herbicides are often unreliable when applied to dense weed populations, because shading and moisture stress from crowding result in

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herbicides

farming



management: Spray fallows

Advances in weed

applications—a grower's

applications-double populations

application strategy

GCTV11: Strategic tillage, does no-till mean

GRDC. Integrated weed management, Section 4: Tactics for managing weed populations. GRDC/CRC for Australian Weed Management, http://www.grdc.com.au/~/media/A4C48127FF8A4B0CA7DFD67547A5B716.

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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



SANTFA: Summer weed control

WeedSmart: Understanding preemergent herbicides

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



GRDC Integrated Weed Management Hub

NGA: Project reports weeds

GRDC: Grain Orana Alliance

- reduced control. Pre-emergent herbicides have the advantage of controlling very small weeds, whereas post-emergent herbicides can be applied to larger, more tolerant/robust plants.
- Crop or pasture type. The choice of crop or pasture species will determine the herbicide selection. For chickpeas, faba beans and lentils, there are few effective, broadleaf post-emergent herbicides. In these cases, it is important to have a plan of attack, which is likely to include the use of a pre-emergent herbicide. The competitive nature of the crop should also be considered. For example, chickpeas, lupins and lentils are poor competitors with weeds and need preemergent herbicides to gain a competitive advantage.
- Soil condition. Soil preparation is a critical first step in the effective use of preemergent herbicides. The soil is the storage medium by which pre-emergent herbicides are transferred to weeds. Soil surfaces that are cloddy or covered in stubble may need some pre-treatment such as light cultivation or burning to prevent 'shading' during application. Too much black ash from burnt stubble may inactivate the herbicide; therefore, ash must be dissipated with a light cultivation or rainfall prior to herbicide application. Less-soluble herbicides such as simazine need to be mixed with the topsoil for best results. This process, called incorporation, mixes or cultivates the top 3–5 cm of soil for uniform distribution of the herbicide in the weed root-zone. Herbicides such as the sulfonylureas and imidazolinones may not need mechanical incorporation, as they move into the topsoil with water (rain or irrigation). Some herbicides need to be incorporated to prevent losses from photodegradation (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. 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) can be as long as 36 months, depending on herbicide, environmental conditions and soil type. 47

Visit Australian Pesticides & Veterinary Medicines Authority for an up-to-date list of registered herbicides.

See NSW DPI Weed control in winter crops (table 7 on pages 42 and 43.)

The choice of herbicides for use in barley will depend on the specific weed species and the crop situation. Consult with your agronomist for further details.

6.12.3 Avoiding crop damage from residual herbicides

When researching the residual activity and cropping restrictions following herbicide application, the herbicide label is the primary source of information and it should be read thoroughly. The information below provides an explanation of how herbicides break down and extra notes on some specific herbicides used in broadacre cropping.

What are the issues?

Some herbicides can remain active in the soil for weeks, months or years. This can be an advantage, in that it ensures good long-term weed control. However, if the herbicide stays in the soil longer than intended, it may damage sensitive crop or pasture species sown in subsequent years.

For example, chlorsulfuron (Glean®) is used in wheat and barley, but it can remain active in the soil for several years and damage legumes and oilseeds.

A real difficulty for growers lies in identifying herbicide residues before they cause a problem. We rely on information provided on the labels for soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if testing is possible, it is too expensive to be part of routine farming practice. Once the crop has

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GRDC. Integrated weed management, Section 4: Tactics for managing weed populations. GRDC/CRC for Australian Weed Management, http://www.grdc.com.au/~/media/A4C48127FF8A4B0CA7DFD67547A5B716.



emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease. ⁴⁸

An option for assessing the potential risk of herbicide residues is to conduct a bioassay involving hand-planting small test areas of crop into the field in question.

Which herbicides are residual?

The herbicides listed in Table 6 all have some residual activity or planting restrictions.

Table 6: Active constituent by herbicide group (may not include all current herbicides)

,		
Herbicide group	Active constituent	
Group B. Sulfonylureas	Chlorsulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)	
Group B. Imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)	
Group B. Triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)	
Group C. Triazines	Atrazine, simazine	
Group C. Triazinones	Metribuzin (Sencor®)	
Group C. Ureas	Diuron	
Group D. Dinitroanilines	Pendimethalin (Stomp®), trifluralin	
Group H. Pyrazoles	Pyrasulfotole (Precept®)	
Group H. Isoxazoles	Isoxaflutole (Balance®)	
Group I. Phenoxy carboxylic acids	2,4-Ds	
Group I. Benzoic acids	Dicamba	
Group I. Pyridine carboxylic acids	Clopyralid (Lontrel®)	
Group K. Chloroacetamides	Metolachlor	
Group K. Isoxazoline	Pyroxasulfone (Sakura®)	

How do herbicides break down?

Herbicides break down via chemical or microbial degradation. The speed of chemical degradation depends on the soil type (clay or sand, acid or alkaline), moisture and temperature. Microbial degradation depends on a population of suitable microbes living in the soil to consume the herbicide as a food source. Both processes are enhanced by heat and moisture. However, these processes are impeded by herbicide binding to the soil, and this depends on the soil properties (pH, clay or sand, and other compounds such as organic matter or iron).

For these reasons, degradation of each herbicide needs to be considered separately and growers need to understand the soil type and climate when trying to interpret recropping periods on the product label for each paddock. ⁴⁹

How can I avoid damage from residual herbicides?

Select an appropriate herbicide for the weed population present. Make sure you consider what the re-cropping limitations may do to future rotation options.

Users of chemicals are required by law to keep good records, including weather conditions, but particularly spray dates, rates, batch numbers, rainfall, soil type and pH



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Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. DEDJTR Victoria, <a href="http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. DEDJTR Victoria, <a href="http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides





(including different soil types in the paddock). In the case of unexpected damage, good records can be invaluable.

If residues could be present, choose the least susceptible crops (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. ⁵⁰

Group B. Sulfonylureas

The sulfonylureas persist longer in alkaline soils (pH >7), where they rely on microbial degradation.

Residual life within the sulfonylurea family varies widely, with chlorsulfuron persisting for \geq 2 years, depending on rate, and not suitable for highly alkaline soils. Triasulfuron persists for 1–2 years and metsulfuron (Ally®) generally persists for <1 year.

Legumes and oilseeds, particularly lentils and medic, are most vulnerable to sulfonylureas. However, barley can also be sensitive to some sulfonylureas—check the label.

Group B. Triazolopyrimidines (sulfonamides)

Debate remains about the ideal conditions for degradation of these herbicides. However, research in the alkaline soils of the Victorian Wimmera and Mallee, and the Eyre Peninsula in South Australia, has shown that the sulfonamides are less likely to persist than the sulfonylureas in alkaline soils. Plant-back periods should be increased in shallow soils.

Group B. Imidazolinones

The imidazolinones are very different from the sulfonylureas; the main driver of persistence is soil type, not soil pH. They tend to be more of a problem on acid soils, but carryover does occur on alkaline soils. Research has shown that in sandy soils, such as on the Eyre Peninsula, they can break down very rapidly (within 15 months in alkaline soils), but in heavy clay soils in Victoria they can persist for several years. Breakdown is by soil microbes. Oilseeds are most at risk. Widespread use of imidazolinone-tolerant canola and wheat in recent years has increased the incidence of imidazolinone residues.

Group C. Triazines

Usage of triazines has increased to counter Group A resistance in ryegrass, in particular in triazine-tolerant canola. Atrazine persists longer in soil than simazine. Both generally persist longer on high pH soils, and cereals are particularly susceptible to damage. Research in the United States indicates that breakdown rates tend to increase when triazines are used regularly, because the number of microbes able to degrade the herbicide can increase. This may mean that breakdown can take an unexpectedly long time in soils that have not been exposed to triazines for some years.

Group D. Trifluralin

Trifluralin tends not to leach through the soil, but it can be moved into the seedbed during cultivation or ridging. Trifluralin binds strongly to stubble and organic matter and is more likely to be a problem in paddocks with stubble retention. Be particularly careful with wheat, oats and lentils. Barley is more tolerant. Use knife-points to throw soil away from seed and sow deep; not suited to disc seeders.





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Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, DEDJTR Victoria, <a href="http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides



Group H. Isoxazoles

Persistence in acid soils (pH <7) has not been fully tested, but research shows that isoxazole persistence is expected to be longer than the label recommendations for legume crops and pastures. Isoxazoles will also persist longer in clay soils and those with low organic matter. Cultivation is recommended prior to re-cropping.

Group I. Phenoxies

Clopyralid and aminopyralid can be more risky on heavy soils and in conservation cropping, where they can accumulate on stubble. Even at low rates they can cause crop damage up to 2 years after application. They cause twisting and cupping, particularly for crops suffering from moisture stress.

2,4-D used for fallow weed control in late summer may cause a problem with autumn-sown crops if plant-back periods are not observed. Changes have been made to the 2,4-D label recently and not all products can be used for fallow weed control—check the label.

The label recommends that you not sow sensitive crops, especially canola, until after a significant rainfall event. Oilseeds and legumes are very susceptible to injury from 2,4-D.

Group K. Metolachlor

Metolachlor is used in canola crops. The replanting interval is 6 months. ⁵¹

Group K. Pyroxasulfone

Pyroxasulfone relies on microbial degradation, which is favoured by in-season rainfall. Label plant-back periods are important particularly for oats, durum wheat and canola. Residues will lead to crop stunting. ⁵²

6.13 In-crop herbicides: knock-downs and residuals

When selecting a herbicide, it is important to know crop growth stage, weeds present and plant-back period. For best results, spray weeds while they are small and actively growing. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur. Check product labels for up-to-date registrations and application methods.

How to get the most out of post-emergent herbicides:

- Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical.
- Consider the growth stage of the crop.
- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species have been in the paddock and the resistance status of the paddock (if unsure, send plants away for a <u>Syngenta Quick-Test</u>).
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought, or, for some chemicals, cloudy or sunny days. This is especially pertinent for frosts with grass-weed chemicals.
- Use the correct spray application:
 - » Consider droplet size with grass-weed herbicides, water volumes with contact chemicals and time of day.
 - » Observe the plant-back periods and withholding periods.
 - » Consider compatibility if using a mixing partner.
 - » Add the correct adjuvant.



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Dual Gold® herbicide, http://www.herbiguide.com.au/Descriptions/hg_Dual_Gold.htm

Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, DEDJTR Victoria, <a href="http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides



For information on cereal growth stages, see <u>GrowNotes Barley South Section 4. Plant growth and physiology</u>.

6.13.1 Herbicide tolerance ratings

Within many broadacre crop species, cultivars have been found to vary in sensitivity to commonly used herbicides and tank mixes, thereby resulting in potential loss of grain yield and reduced farm profit. With funding from GRDC and state government agencies across Australia, trials into cultivar x herbicide tolerance are conducted annually.

The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species including wheat, barley, triticale, oats, lupins, field peas, lentils, chickpeas and faba beans. The intention is to provide data from at least 2 years of testing at the time of wide-scale commercial propagation of a new cultivar.

Fortunately, >70% of all crop varieties are tolerant to most herbicides. The remaining varieties can experience yield losses of 10–30%, and in some cases, 50% yield loss has been recorded. This occurs with the use of registered herbicides applied at label rates under good spraying conditions at the appropriate crop growth stage.

To provide growers with clear information about the herbicide interactions of a variety for their region, four regionally based, herbicide-tolerance screening projects were established. The four projects have recently been combined under a national program.

6.13.2 Post-emergent herbicide damage

Crop yield can be compromised by damage from herbicides, even when products are applied according to the label rate.

Factors that can contribute to herbicide damage are:

- crop variety grown
- weather conditions at time of application
- mixing partner
- · growth stage of crop
- nutritional status of crop

6.14 Selective sprayer technology

A new permit in place across Australia will help growers to tackle herbicide-resistant grasses with weed-detecting technology.

Increased use of no-till cropping and an increasing incidence of summer rain have stimulated many growers to include a predominantly glyphosate fallow over summer to remove weeds and conserve moisture for the next crop.

To reduce the risk of glyphosate resistance developing in fallow weeds, some growers are using weed-detecting technology to detect individual weeds that have survived the glyphosate application and spraying these with an alternative knockdown herbicide.

The key to successful resistance management is killing the last few individuals, but this is difficult on large-scale properties. Left uncontrolled, these last few weeds result in significant seed production and a resetting of the weed seedbank.

The introduction of weed-detecting technology is timely, because it is well suited to detecting patches of weeds across large areas. Sales of the two systems available in Australia, WeedSeeker® and WEEDit®, have increased by at least 30% annually over the past 2 years.

The technology uses optical sensors to turn on spray nozzles only when green weeds are detected, greatly reducing total herbicide use per hectare (Figure 13). The units have their own light source so can be used day or night.



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Rather than spray a blanket amount of the herbicide across a paddock, the weed-detecting technology enables the user to apply higher herbicide rates (per plant), which results in more effective weed control and saves on herbicide costs.



Figure 13: Selective sprayer technologies use optical sensors to turn on spray nozzles only when green weeds are detected. (Photo: CropOptics)

6.14.1 Special permit

Weed-detecting technology (via WeedSeeker®) is being used to manage glyphosate-resistant grasses in northern New South Wales fallows with the aid of a minor use permit. This allows growers in the region to use selective grass herbicides and higher rates of paraquat and diquat (bipyridyl herbicides, Group L). The permit (PER11163) is in force until 28 February 2019 to cover all Australian states.

The permit allows the use of about 30 different herbicides from groups with seven MOA. Additional MOAs are likely to be added to the permit over time.

Some herbicide rates have been increased to enable control of larger or stressed weeds. For example, the glyphosate 450 (450 g glyphosate/L) rates are 3–4 L/ha (using a set water rate of 100 L/ha), which exceeds the label blanket rates of 0.4–2.4 L/ha. Similar increases in rate have also been permitted for paraquat (Gramaxone®).

The WeedSeeker® permit system is a lifesaver for no-till and minimum-tillage systems battling glyphosate-resistant weeds. It represents a more economical way to carry out a double-knock and avoids the need to cultivate for weed-seed burial. It also results in significant savings in chemical costs.

The new technology also has the potential to map troublesome weed patches so that these areas can be targeted with a pre-emergent herbicide before sowing. 53

For more information on fallow weed control, see <u>GrowNotes Barley South Section 1.</u> <u>Planning and paddock preparation</u>.

An area of weed management that many farmers fail to implement is the stopping of unwanted seeds and propagules (corms, tubers, etc.) coming onto, or being spread within, the property. This has led to the introduction of a new species of weed, or one with glyphosate or paraquat resistance from external or internal sources.

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T Cook (2013) Selective spraying to cut costs. GRDC Ground Cover Supplements, 6 May 2013, http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS104/Selective-spraying-to-cut-costs



6.15 Strategies to stop the spread of weeds

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.

6.15.1 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 usually 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.

To avoid these problems follow the following guidelines:

- · Know the weed status of any farm from which you buy seed.
- Plan seed purchases ahead of time and inspect the paddock where the seed is being grown.
- Obtain a sample of the seed and have it analysed for weed seed contamination and germination.
- Determine the herbicide-resistance status of weeds present on the source farm and paddock, and avoid purchasing seed from paddocks with known resistance.
- Grade seed to reduce weed numbers. 54

6.15.2 Manage weeds in non-crop areas

Weed infestations often commence in non-crop areas (e.g. around buildings, along roadsides, along fencelines, around trees) (Figure 14). 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 such as fleabane and sowthistle.

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. ⁵⁵



information

IWM section 4: Tactics

IWM section 4: Tactics



⁵⁵ GRDC (2014) Section 7. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-7-Managing-farm-hygiene



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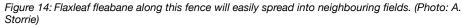
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More information

IWM section 4: Tactics



6.15.3 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 that machinery and vehicles have been cleaned prior to entry on the farm, or cleaned at a specially designed wash station. Within the farm, harvest from cleanest to dirtiest paddock to minimise the spread of weed seeds. Where breakdowns require in-field repair, mark the position with a GPS and diary to check for weed germinations. ⁵⁶

More information

IWM section 4: Tactics

More information

IWM section 4: Tactics

6.15.4 Livestock feeding and movement

Weeds can be introduced in stock feed and in livestock over long distances, particularly during droughts. Ensure that you know the source of fodder. New stock or stock returning from agistment need to be kept in a holding paddock for 7 days to enable the bulk of seed in their intestines to be excreted. ⁵⁷

6.15.5 Monitor paddocks following flood inundation

Floods and inundation of fields are a common source of new weed infestations through the transport of seeds and vegetative propagules such as stolons, rhizomes and tubers (Figure 15).

Effective monitoring to identify new weed incursions and patches is needed. Handroguing a few plants every year can help when weed numbers are very low, even on very large properties. ⁵⁸





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

⁵⁷ GRDC (2014) Section 7. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-7-Managing-farm-hygiene

⁵⁸ GRDC (2014) Section 7. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-7-Managing-farm-hygiene



IWM section 4: Tactics

AWC: Risk of weed movement through vehicles, plant and equipment: results from a Victorian study

CottonInfo: Come Clean Go Clean

Farm biosecurity: Grains

AWC: Seed box survey of field crops in Victoria during 1996 and 1997

AWC: Weed seed contamination in cereal and pulse crops



GRDC webinar on managing weeds on **fencelines**

Weed seed bank destruction-farm hygiene and weed management



Figure 15: 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. (Photo: A.





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SECTION 7

Insect control

Insect and other arthropod pests that can pose a problem include blue oat mite (Penthaleus spp.), redlegged earth mite (Halotydeus destructor), Bryobia mites (Bryobia spp.), Balaustium mite, cutworms, aphids, earwigs, armyworms, Helicoverpa spp., pasture webworm, pasture cockchafers, grass anthelids, lucerne flea (Sminthurus viridis), leaf hoppers, slugs, snails, millipedes, slaters and locusts (Tables 1 and 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 nose a risk to cereal crops 2

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	Information on pest numbers prior to sowing from soil sampling, trapping and/or baiting will inform management Implementation of integrated slug management strategy (burning stubble, cultivation, baiting) where there is a history of slugs	Slugs and snails are rare on sandy soils
Summer volunteers and <i>Brassica</i> weeds will increase slug and snail numbers	Increased sowing rate to compensate for seedling loss caused by establishment pests	
Cold, wet establishment conditions expose crops to slugs and snails		
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	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
History of high mite pressure Aphids		procedio
Higher rainfall areas where grass weeds are present prior to sowing—higher risk of <i>Barley yellow dwarf virus</i> transmission by aphids Wet summer and autumn promoting 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 Use of seed dressings can reduce levels of virus transmission and delay aphid colonisation Use of SPs and OPs 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

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/integratedpest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals





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NIPI. Winter cereals. NIPI IPM guidelines, http://ipmguidelinesforgrains.com.au/crops/winter-cereals/





cesar: Insect gallery

NIPI: Insect identification aids

GRDC Update Papers:
Don't forget the good
guys—recognising and
identifying beneficial
insects in your paddock

cesar: PestFacts: Grass anthelids

GRDC Ute Guides: Insects

GRDC Update
Papers: Insect pests—
resistance, virus vectors
and lessons from 2014

Table 2: Incidence of pests of winter cereals 3

Present, present in crop but generally not damaging; Damaging, crop susceptible to damage and loss; snails are also a grain contaminant at harvest

		Cro	p stage	
	Emergence	Vegetative	Flowering	Grainfill
<u>Wireworms</u>	Damaging	Present		
<u>Cutworm</u>	Damaging			
Black headed cockchafer	Damaging	Present		
Earth mites	Damaging	Present		
Slugs, snails	Damaging			
Brown wheat mite		Damaging		
<u>Aphids</u>	Present	Damaging	Present	Present
<u>Armyworm</u>		Present- damaging	Present	Damaging
Helicoverpa armigera				Damaging

Stay informed about invertebrate pest threats throughout the winter growing season by subscribing to SARDI's PestFacts South Australia and cesar's PestFacts south eastern.

Subscribers to PestFacts also benefit from special access to **cesar**'s extensive Insect Gallery, which can be used to improve skills in identifying pest and beneficial insects.

Use Tables 3 and 4 below to identify damage caused by key pests, and to assess risk and determine control measures for establishment pests.

Table 3: Crop damage pest identification key for the Southern Region—cereals ⁴

Table 3: Crop damage pest identification key for the Southern Region—cereals ⁴		
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	
Leaves or plants cut off and lying on the ground or protruding from small holes next to plants. Slender larvae, up to 35 mm long, construct silk-lined tunnels that protrude above ground to form chimneys.	Pasture tunnel moth*	
Leaves or plants cut off and lying on the ground or protruding from small holes next to plants. Larvae are brown with black and yellow marking, covered in tufts of stout hairs and can grow up to 50 mm in length.	Grass anthelid*	
Leaves of young seedlings fed upon or damaged; in severe cases seedlings are ring-barked at ground level causing them to drop. Adults are 3-5 mm long, round and dull brown resembling small clods of dirt.	Mandalotus weevil*	
Plants eaten close to or below ground level causing plant death and bare patches within the crop.	Polyphrades weevil*	
Larvae emerge from tunnels with rain events to feed on foliage. Can cause bare patches in crops during late autumn and early winter. 'C' shaped larvae with six legs and a black to brown head capsule.	Blackheaded pasture cockchafers*	
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	
Grasshoppers and locusts.	Grasshoppers and locusts	

NIPI (2014) Winter cereals. NIPI IPM guidelines, http://ipmguidelinesforgrains.com.au/crops/winter-cereals/





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GRDC (2012) I spy. Insects of Southern Australian Broadacre Farming Systems Identification Manual and Education Resource. GRDC, http://grdc.com.au/Resources/Bookshop/2012/11/I-SPY



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 8-legged (nymphs have 6 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
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 ⁵

IADI	e 4: Establishment pests of the Sout	rierri negiori—risk assessirierit a	and management
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 postemergent insecticide treatment If low risk: avoid insecticide seed dressings (esp. 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



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NIPI (2014) Establishment pests—Southern Region. 'Best bet' IPM strategy. NIPI IPM Workshops, http://ipmworkshops.com.au/wp-content/uploads/BestBet_EstablishmentSouth2014.pdf





Pre-sowing	Emergence	Crop establishment
If high risk: burn stubbles cultivate worst areas remove weeds in paddocks/ along fencelines 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/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
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
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 black headed pasture cockchafer, spray around heavy dews or light rainfall which will trigger larvae activity	Resowing may be an option, but some species have a 2-year life cycle, so larvae can persist through winter into spring. ID will guide this decision
des, weevils		
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
	If high risk: burn stubbles cultivate worst areas remove weeds in paddocks/ along fencelines 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/after sowing prior to emergence 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 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	If high risk: • burn stubbles • cultivate worst areas • remove weeds in paddocks/ along fencelines 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/after sowing prior to emergence 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 Dig soil within paddock to determine incidence of scarab larvae. If high risk: • cultivate land a void 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 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 Limited options for control once crop is sown. Consider resowing severely affected areas of crop Assess risk. High risk when donce crop is sown. Consider resowing severely affected areas of crop Assess risk. High risk when donce or pis sown. Consider resowing severely affected areas of crop Assess risk. High risk under cold conditions and with slow 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 Limited options for control once crop is sown. Larvae of most species do not emerge from the soil. For black headed pasture cockafer, spray around heavy dews or light rainfall which will trigger larvae activity des, weevils If high risk: • burn stubbles



More information

NIPI IPM Workshops: Establishment pests—Southern Region

NIPI IPM Workshops: Decision making for insect management in grain crops



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7.1 Integrated pest management

Pests are best managed by using an integrated pest management (IPM) approach. 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.

The IPM approach 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 only as a last resort. IPM relies on monitoring the crop regularly, having pests and beneficial insects correctly identified, and making strategic control decisions according to established damage thresholds. ⁶

Key IPM strategies:

- Where the risk of establishment pest incidence is low (e.g. earth mites), regular monitoring can be substituted for the prophylactic use of seed dressings.
- Where establishment pests and aphid infestations are clearly a result of invasion from weed hosts around the field edges or neighbouring pasture, a border spray of the affected crop may be sufficient to control the infestation and allow the build-up of natural predators.

Insecticide choices:

- Redlegged earth mites, blue oat mites, and other mite species can occur in mixed populations. Determine species composition before making decisions because they have different susceptibilities to chemicals.
- Establishment pests have differing susceptibilities to insecticides (synthetic
 pyrethroids (SPs) and organophosphates (OPs) in particular). Be aware that the use
 of some pesticides may select for pests that are more tolerant.

Insecticide resistance:

- Redlegged earth mites have been found to have high levels of resistance to SPs such as bifenthrin and alpha-cypermethrin.
- Helicoverpa armigera has historically had high resistance to SPs, but H. punctigera, more common in the south, does not have SP resistance. The inclusion of nuclear polyhedrosis virus (NPV) is effective where mixed populations of armyworm and Helicoverpa occur in maturing winter cereals.

7.2 Aphids

Aphids are vectors of *Barley yellow dwarf virus* (BYDV), a major problem in wet areas in southern 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. ⁸ 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 of aphids start to build within the crop. In Australia, all aphids in a cereal crop are females, able to give birth to live young without the need to mate. The immature aphid nymphs have several growth stages and moult at each stage into



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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

⁷ NIPI (2014) Winter cereals. NIPI IPM guidelines, http://ipmguidelinesforgrains.com.au/crops/winter-cereals/

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



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 around the plant's base, up onto the leaves and stems as the crop starts elongation (Figure 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. Both are characterised by a dark reddish patch on the tip of the abdomen.



Figure 1: Heavy infestation of oat aphids (Rhopalosiphum padi).

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Table 5: Oat or wheat aphid management summary 9

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, and in high densities 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

7.2.2 Corn aphid (Rhopalosiphum maidis)

Corn aphids are most likely to be found in barley crops, but 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 (Figure 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).



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DAF Qld (2011) Oat aphid, wheat aphid. Department of Agriculture and Fisheries Queensland, <a href="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





Figure 2: Corn aphids (Rhopalosiphum maidis).

Table 6: Corn aph	iid management summary ¹⁰
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 throughout the cereal belt
	Risk period: Most prevalent on cereals in late winter and early spring. High numbers often occur in years when an early break in the season and mild weather in autumn and early winter provide 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 <u>Pest Genie</u> or <u>APVMA</u> 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





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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



7.2.3 Rose-grain aphid (Metopolophium dirhodum)

The rose-grain aphid (Figure 3, Table 7) tends to colonise the underside of leaves higher on the plant. Adults are up to 3 mm long, and are large and pale aphids with a dark stripe down the midline of the back. Clusters of juveniles are common on leaves.



Figure 3: Rose-grain aphids (Metopolophium dirhodum), adult and nymphs.

Table 7: Rose-grain aphid management summary 11

Table 7: Rose-gra	ain aphid management summary 11
Scientific name	Metopolophium dirhodum
Description	Adults are 3 mm long, green to yellow-green with long and pale siphunculi (tube-like projections on either side at the rear of the body) and may have wings. There is a dark green stripe down the middle of the back. Antennae reach beyond the base of the siphunculi. Nymphs are similar but smaller
Similar species	Because of its distinctive colour, it is unlikely to be confused with other aphids
Distribution	An introduced species that has been recorded in New South Wales, Queensland, South Australia, Tasmania and Victoria
Crops attacked	Wheat, barley, triticale, oats
Life cycle	Undergoes many generations during the growing season; winged and non-winged forms occur
Damage	Adults and nymphs are sap-suckers. Under heavy infestations, plant may turn yellow and appear unthrifty. Can spread BYDV in wheat and barley
Monitoring and action level	Can affect any crop stage; assess the potential for direct-feeding damage in late winter. Estimate the number of aphids per tiller. Aphids are unlikely to cause economic damage to cereal crops expected to yield <3 t/ha
Control	Chemical control: Apply a foliar insecticide in late winter or spring to avoid damage to tillers. To prevent losses from BYDV in virus-prone areas, control aphids early in the cropping year. For current chemical control options see Pest Genie or APVMA
	Cultural control: There are no known effective cultural control methods for this aphid

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DAF Qld (2011) Rose-grain 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-pestlist/aphid-overview/rose-grain-aphid

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GRDC Fact Sheets:

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cesar PestNotes

southern: Oat aphid

southern: Corn aphid

Region

Cereal aphids. Northern



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7.2.4 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 not a threshold for BYDV transfer.

7.3 **Armyworm**

Armyworms are the caterpillar stage of certain moths, 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 after sunset to feed on the leaves of all winter cereals, particularly barley and oats, generally during September and October. 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.



Figure 4: Common armyworm (Leucania convecta). (Photo: DAF Qld)

The most prevalent species in the Southern Region are the common armyworm (Leucania convecta, Figure 4) and inland and southern armyworms (Persectania dyscrita and Persectania ewingii). Infestations are evident from scalloping on margins of leaves caused by feeding of the older larvae. Larvae target the stem node as the leaves become dry and unpalatable, and 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. One larva/m² can cause a grain loss of 70 kg/ha.day (Table 8). Larvae take ~8-10 days to develop through the final, most damaging instars, with crops susceptible to maximum damage for this period

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

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the base of damaged plants where the larvae may be sheltering in the soil during the day. Using a sweep net (or swing 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 m² 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, whereas small larvae in late crops that are still green and at early seedfill may reach a damaging size in time to reduce crop yield significantly.

Control is warranted if the armyworm population distributed throughout the crop is likely to cause the loss of 7–15 heads/m². Many chemicals will control armyworms. However, their effectiveness often depends on good penetration into the crop to achieve contact with 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. ¹²

Table 8: Value of yield loss incurred by armyworm larvae (1 or 2/m²) per day, based on various values for grain and an estimated loss, given 1 larva/m², of 70 kg/ha

Considering these results, and the relatively low cost of controlling armyworm, populations of >1 large larva/m² in ripening crops warrant spraying

	Value of yield loss	s (\$) per ha per day
Value of grain (AU\$/t)	1 larva/m²	2 larvae/m²
\$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



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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: Armyworm management summary 13

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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. Crowded larvae are usually darker than uncrowded. 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 all 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 1000 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
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 m². 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/m² 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. 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)



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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

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southern: Corn earworm

budworm

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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 carab 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

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. *Helicoverpa punctigera* is widespread in southern Australia and common on pulse crops and canola, but rarely found on cereal crops. *Helicoverpa armigera* (Figure 5) is primarily a pest in the northern grains region but does occur in the south, particularly in irrigated crops in northern Victoria. It can occasionally be found grazing wheat and barley heads. ¹⁴

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).



Figure 5: Helicoverpa armigera.

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GRDC (2102) Approaches to key insect pests of southern and western grains. Southern and Western Regions. Insecticide Management and Invertebrate Pest Identification Fact Sheet, GRDC, <u>July 2012, https://www.grdc.com.au/~/media/23FC4F7A6F794888B239CB4080A1DAFF.pdf</u>



7.5 Blue oat mite (*Penthaleus* spp.)

Blue oat mites (Figure 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 10). Blue oat mites are most easily seen in the cooler part of the day, or in cloudy conditions. 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 the presence of 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 reduction in 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. The use of control tactics solely in spring will not prevent the carry-over 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. ¹⁵

The blue oat mite is an important pest of seedling winter cereals. When infestations are severe, the leaf tips wither and eventually the seedlings die. Eggs laid in the soil hibernate over winter, allowing populations to build up over a number of years. This can cause severe damage if crop rotation is not practised.



Figure 6: Blue oat mite (Penthaleus sp.). (Photo: A Weeks, cesar)

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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 10: Management summary for blue oat mite 16

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 presence of a small red area on the back distinguishes it from the redlegged earth mite
Similar species	Brown wheat mite, redlegged earth 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 2–3 weeks of emergence in autumn. The use of control tactics solely in spring will not prevent the carry-over of eggs into the following autumn. For current chemical control options see Pest Genie or APVMA
Natural enemies	Thrips and ladybirds

7.6 Lucerne flea (Sminthurus viridis)

Lucerne flea is an important pest of establishing crops. It is identified by its action 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 that monitoring is sufficient to detect localised patches or 'hot spots'. Seek advice on management and spray strategies. ¹⁷



Figure 7: Adult lucerne flea (Sminthurus viridis). (Photo: cesar)

7.6.1 Description

Adult lucerne fleas are globular, wingless insects, 2–3 mm long with green, brown and yellow markings (Figure 7). They appear yellow-green to the naked eye, although their

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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

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/ data/assets/pdf file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

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globular abdomens are often a mottled pattern of darker pigments. They make jumping movements when disturbed. Nymphs resemble the adults except in size. 18

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.

Lucerne fleas have a wide host range. They will attack most broadacre crops, including canola, lucerne, pastures, cereals and some pulses. Feeding results in the appearance of distinctive transparent 'windows'. They are generally a problem in regions with loam or clay soils.

Crops should be inspected frequently at, and immediately following, emergence, when most susceptible to damage. 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.

7.6.3 **Impact**

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.

7.6.4 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 upon 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. 19

Snout mites (which have orange bodies and legs) are effective predators of lucerne fleas, particularly in pastures, where they can prevent pest outbreaks. The complex of beneficial species (including snout mites) should be assessed before deciding on control options. 20

Several options are available to growers for controlling the lucerne flea. Foliar insecticides can be applied ~3 weeks after lucerne fleas have been observed in a newly emerged crop. This will allow for further hatching of oversummering eggs but will be before lucerne fleas reach the adult stage and begin to lay winter eggs. If spraying is required, do not use SPs.

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

GRDC Grain Research Advice: Knowledge, timing, key to lucerne flea control

NIPI IPM Guidelines: Lucerne flea in winter seedling crops

GRDC: Canola best practice management guide. Lucerne flea (p. 51)

NIPI: I Spy Manual. Lucerne flea (section 4, pp. 63-64)



CropPro. Lucerne flea. Pests in canola. CropPro, http://www.croppro.com.au/cb_pages/pests in canola in crop.php?category id=2374



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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/





7.7 NGA trials—managing aphids

7.7.1 Varietal resistance or tolerance

In 2008, the Northern Growers Alliance (NGA) in association with Industry & Investment NSW conducted trials at four locations on three barley varieties (Fitzroy®, Grout® and Gairdner®), assessing the impact and economics of managing aphids. Trial results showed that oat, corn and rose-grain aphid populations were not influenced by barley variety. ²¹

In virus-prone areas, growers are advised to use resistant plant varieties to minimise losses due to BYDV. $^{\rm 22}$

7.7.2 Damage caused by pests

Aphids can damage barley crops in two ways: by stressing the crop, particularly if it is suffering from lack of moisture, and by spreading BYDV. In the absence of BYDV, aphids affect cereal plants by direct feeding, effectively creating a nitrogen sink, diverting nitrogen away from the developing and filling grain. Aphids use the nitrogen for their growth and reproduction. ²³ Oat aphids appear to affect yield by reducing the number of viable tillers. ²⁴

Infection with BYVD in barley causes a characteristic bright yellowing of leaves (particularly older leaves) and interveinal chlorosis starting from the leaf tips and moving towards the base. In some varieties, reddening of leaf tips may also develop. Late infections do not result in severe stunting but young leaves may turn yellow. ²⁵

Early BYDV infections of cereal plants will mean that they have less aboveground biomass and a less extensive root system. Grain size may be reduced or grain may become shrivelled, which causes lower yields, higher screenings and reduced marketing options. Researchers in the northern grains region have found it difficult to detect symptoms of BYDV by visual inspection because the signs are similar to those of heavy aphid infestation or moisture stress. ²⁶

Aphids transmit BYDV from plant to plant. When aphids feed on plants, their mouthpart (stylet) penetrates the leaf epidermis and enters the plant's vascular system—the phloem. Within 15 minutes of feeding, the aphid contracts the virus if the plant is already infected, or transmits the disease to an 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 that an infected aphid will transmit the virus for the rest of its life. The virus survives from one season to the next

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P Daniel (2009) Aphids in winter cereals—just a nuisance or an economic pest? Northern Grower Alliance, Sept. 2009, http://www.nga.org.au/results-and-publications/download/39/australian-grain-articles/pests-1/aphids-in-barley-september-2009.pdf

DAF Qld (2011) Oat aphid, wheat aphid. Aphids in field crops. Department of Agriculture and Fisheries Queensland, <a href="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

M Miles (2009) Winter cereal aphids—a researcher's view. Northern Grower Alliance, Sept. 2009, http://www.nga.org.au/results-and-publications/download/39/australian-grain-articles/pests-1/aphids-in-barley-september-2009.pdf

²⁴ GRDC (2010) Aphid control in cereals can pay. Northern Region. Cereal Aphids Fact Sheet, GRDC, July 2010, http://www.grdc.com.au/uploads/documents/GRDC_FS_CerealAphids1.pdf

S Simpfendorfer (2010) Barley yellow dwarf virus widespread in northern NSW in 2009. GRDC Update Papers, 24 September 2010, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/BARLEY-YELLOW-DWARF-VIRUS-WIDESPREAD-IN-NORTHERN-NSW-IN-2009

GRDC (2010) Aphid control in cereals can pay. Northern Region. Cereal Aphids Fact Sheet, GRDC, July 2010, http://www.grdc.com.au/uploads/documents/GRDC_FS_CerealAphids1.pdf



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. ²⁷

7.7.3 Thresholds for control

Evidence suggests there is a case to use seed treatments in barley. In NGA trial years of 2008 and 2009, the need to apply a foliar spray later in the season was high where a seed treatment was not used.

Aphids can affect any crop stage but are unlikely to cause economic damage to cereal crops expected to yield <3 t/ha. Consider treatment if there are >10-20 aphids on 50% of the tillers. 28

NGA trials in 2008, 2009 and 2010 were designed in part to suggest a suitable aphid threshold for foliar insecticide application. A spray threshold of 10 aphids/tiller appears realistic, but spraying needs to be made on an increasing aphid population and where beneficial insect activity is limited. ²⁹

Note: Economic thresholds should be used as a guide to implementing a control strategy when the cost of the potential damage outweighs the cost of control. However, for aphids it can be difficult to determine thresholds because many factors will influence the damage caused by a given aphid density. For example, local weather conditions, the growth stage of the crop, the crop's yield potential, the time remaining until harvest and the potential transmission of aphid-vectored plant viruses can all be important considerations. For these reasons, economic thresholds for aphids have the potential to differ substantially between regions and over time. ³⁰

7.7.4 Management of aphids

Overall results from NGA trials in 2008, 2009 and 2010 showed that seed treatment provided more consistent yield and economic benefits than foliar applications in controlling aphids in barley, and that imidacloprid seed treatments should be considered as a management option for growers in situations of higher aphid pressure.

The trials evaluated the efficacy of seed treatments containing imidacloprid, the insecticidal active ingredient in Bayer CropScience products Hombre® (tebuconazole + imidacloprid), Zorro® (triadimenol + imidacloprid) and Gaucho®. The manufacturer claims that its own trials in Australia proved imidacloprid to stimulate the plant's production of 6-CNA, an inherent growth booster, which can be limited by environment stresses such as extended dry periods. The manufacturer also claims that Hombre® and Zorro® can be used to improve yields of wheat, barley and oats. ³¹

These claims appear to be supported by the NGA results.

The results are summarised below.

Aphid population:

Aphid pressure was rated as moderate in 2009, with >10 aphids/tiller at six of 10 sites and peak counts at 25–50/tiller.

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GRDC (2013) Management tips to avoid yield penalties. Southern Region. Barley Yellow Dwarf Virus Fact Sheet, GRDC, August 2013, https://www.grdc.com.au/~/media/A4741C713F5C486B9907F96745BF2EEE.pdf

DAF Qld (2011) Oat aphid, wheat aphid. Aphids in field crops. Department of Agriculture and Fisheries Queensland, <a href="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

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K Blowers (2009) Imidacloprid, the insecticidal active ingredient in Hombre and Zorro is more than just an insecticide. GRDC Update Papers 16 Sep 2009, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2009/09/IMIDACLOPRID-THE-INSECTICIDAL-ACTIVE-INGREDIENT-IN-HOMBRE-AND-ZORRO-IS-MORE-THAN-JUST-AN-INSECTICIDE



- Aphid pressure was rated as low in 2010, with ~5–10 aphids/tiller found at all four sites.
- Three different aphid species were found at nearly all sites, but varied in population dynamics and timing.
- Oat and rose-grain aphids were found in similar numbers in wheat, durum and barley crops, but the corn aphid was almost exclusively found in barley.
- Populations generally built up and naturally declined within about 3–4 weeks.
- High levels of beneficial insects (wasps and ladybirds) were seen at a number of sites and appeared to initiate population declines.

Aphid control:

- The standard label rate of imidacloprid seed treatment (e.g. Zorro® at 400 mL/100 kg) provided extended aphid control of ~70–90 days after planting.
- The high label rate of imidacloprid seed treatment (e.g. Emerge®) at 240 mL/100 kg) extended aphid suppression by about an additional 10–14 days.
- Pirimor® (pirimicarb) provided good levels of knockdown control.

Yield and grain quality impact:

- The standard rate of imidacloprid resulted in mean yield benefits of ~6% (150–200 kg/ha) at sites with aphid pressure of >5 aphids/tiller during both 2009 and 2010.
- In 2008, with higher aphid pressure (>70 aphids/tiller at all four site), the same rate provided yield benefits of about 10% (330 kg/ha).
- Increased yield benefit was obtained with the high rate of imidacloprid.
- Level of benefit was reduced at sites with low aphid pressure (unsprayed sites).
- Pirimicarb resulted in mean yield benefits of ~2–4% or 100–150 kg/ha.
- No consistent impact was found on grain quality from any treatment.

Net economic benefit:

- The standard rate of imidacloprid resulted in mean net benefits of about \$20–30/ha at sites with aphid pressure of >5 aphids/tiller during both 2009 and 2010.
- In 2008, with higher aphid pressure (>70 aphids/tiller in all four trials), the same rate provided net benefits of about \$37/ha at a grain price of \$125/t.
- Mean net benefit was about \$9/ha at unsprayed sites with low aphid pressure.
- Increased net benefit was obtained with the high rate of imidacloprid.
- Mean net benefit from pirimicarb was about \$5/ha in both years.

Trials have shown that a greater understanding of the aphids' natural enemies is required to ensure that foliar spraying is not applied when predation by insects (including hoverflies, lacewings and ladybirds) and parasitism by wasps can reduce

aphid populations. However, killing or driving out of aphids by other insects cannot be relied upon in every season. Heavy rain may reduce aphid populations significantly.

More information

NGA: Aphid management in barley 2008





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SECTION 8

Nematode management

Root-lesion nematodes (RLN; *Pratylenchus* spp.) are microscopic, worm-like animals that extract nutrients from plants, causing yield loss. In the southern grains region, the predominant RLN are *P. thornei* and *P. neglectus*.

Resistance and susceptibility of crops can differ for each RLN species. A tolerant crop yields well when large populations of RLN are present (the opposite is intolerance). A resistant crop does not allow RLN to reproduce and increase in number (the opposite is susceptibility). ¹

Pratylenchus penetrans and P. crenatus have been reported, but at a very low frequency; P. quasitereoides (formerly known as P. teres) has been identified only in crops in Western Australia and is not known to occur in other regions of Australia. Other species of RLN may occur, and if this is suspected, you should follow up with your state department of agriculture.

Cereal cyst nematode (CCN; *Heterodera avenae*) is a damaging pathogen of broadacre cereal crops in South Australia and Victoria. It affects wheat, barley, oats and triticale, and can cause yield losses of up to 80%. The damage caused by the feeding nematode results in a proliferation of roots at the feeding site, which forms a knot in the root, giving the plant the characteristic symptoms. CCN has been successfully managed by growing resistant cereal varieties.



GRDC Tips and Tactics:
Root-lesion nematodes

8.1 About nematodes

Root-lesion nematodes use a syringe-like 'stylet' to extract nutrients from the roots of plants (Figure 1). Plant roots are damaged as RLN feed and reproduce inside plant roots. *Pratylenchus thornei* and *P. neglectus* are the most common RLN species in Australia. Nematodes can be found deep in the soil profile (to 90 cm depth) and are found in a broad range of soil types, from heavy clays to sandy soils. Barley is susceptible to *P. thornei* and moderately susceptible to *P. neglectus*. ^{2,3}

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. ⁴





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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

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

³ GRDC (2009) Managing cereal cyst and root lesion nematodes. Southern and Western Region. Plant Parasitic Nematodes Fact Sheet, GRDC, https://www.grdc.com.au/~/media/BA7FDD8CD34344BB94544A4337C45E26.pdf

M Thomson (2014) New light shed on root lesion nematodes. GRDC Media Centre 13 January 2014, http://grdc.com.au/Media-Centre/Media-News/North/2014/01/New-light-shed-on-root-lesion-nematode



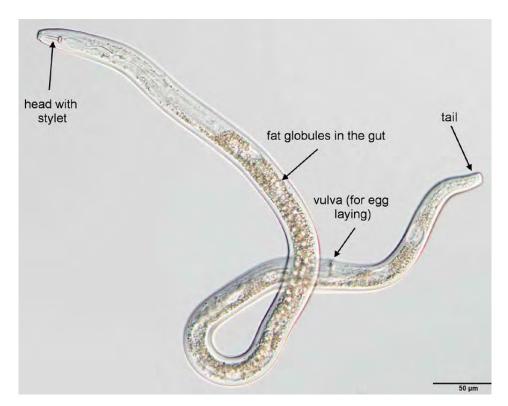


Figure 1: Pratylenchus thornei adult female viewed under the microscope. The nematode is approximately 0.65 mm long.

8.1.1 Life cycle

In the Southern Region, 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 2).

As the nematodes feed and multiply, lesions (sections of brown discoloration) are formed in the cortex of the plant root.

Eggs are laid within the root or soil, and the first larval stage and moult occur within the egg. Second-stage larvae emerge from eggs and undergo three more moults before reaching adulthood.

There may be 3–5 RLN life cycles within the plant each growing season, depending on temperature and moisture. The optimum temperature for nematode reproduction is $20^{\circ}-25^{\circ}$ C. The life cycle is generally completed in 40–45 days (~6 weeks) depending on temperature.

As the plants and soil dry out in late spring, RLN enter a dehydrated survival state called anhydrobiosis. In this state, nematodes can survive high soil temperatures of up to 40°C and desiccation over summer. RLN can survive many years in this dehydrated state if the soil remains dry. Nematodes can also survive in root pieces.

More than one RLN species can be found in the roots of an individual crop, although one species usually dominates.



Know more. Grow more.

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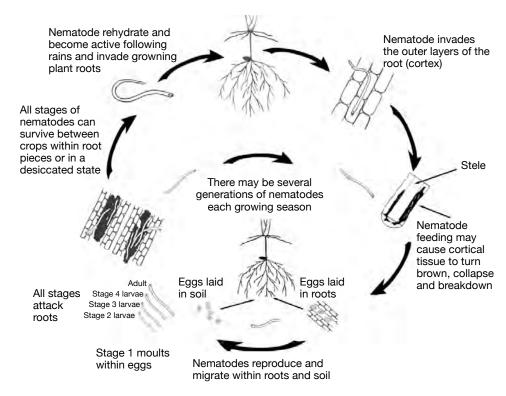


Figure 2: Disease cycle of root-lesion nematode; adapted from: GN Agrios (1997) Plant pathology, 5th edn (Academic Press: New York). (Illustration by Kylie Fowler)

8.1.2 Economic importance

In the Southern Region, high densities of RLN can cause significant yield losses in barley, as shown in trials on the Eyre Peninsula, South Australia. ⁵ The extent of damage, and subsequent grain yield loss, depend on site, seasonal conditions, the tolerance of the crop and the numbers of nematodes present at sowing.

8.2 Varietal resistance or tolerance

A tolerant crop yields well when large populations of RLN are present (in contrast to an intolerant crop). Many barley varieties are moderately tolerant. A resistant crop does not allow RLN to reproduce and increase in number (in contrast to a susceptible crop) (Table 1).

Table 1: Susceptibility and resistance of various crops to root-lesion nematodes 6

RLN species	Susceptible	Intermediate	Resistant
P. thornei	Wheat, chickpeas, faba beans, barley, mungbeans, navy beans, soybeans, cowpeas	Canola, mustard, triticale, durum wheat, maize, sunflowers	Canary seed, lablab, linseed, oats, sorghum, millet, cotton, pigeon peas
P. neglectus	Wheat, canola, chickpeas, mustard, sorghum (grain), sorghum (forage)	Barley, oat, canary seed, durum wheat, maize, navy beans	Linseed, field peas, faba beans, triticale, mungbeans, soybeans

Field work by the Northern Grower Alliance suggests that differences in resistance between current commercial barley varieties are much smaller than in wheat. Most barley varieties appear to fall into the medium-risk category for building up *P. thornei*



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K Linsell et al. (2015) Tolerance and resistance of cereals to root lesion nematode Pratylenchus thornei on Eyre Peninsula. Eyre Peninsula Farming Systems 2014 Summary. SARDI/GRDC, http://eparf.com.au/wp-content/uploads/2015/04/4j-Tolerance-and-resistance-of-cereals-to-Pratylenchus-thornei.pdf

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

More

EPFS: Tolerance and

root lesion nematode

Eyre Peninsula

resistance of cereals to

Pratylenchus thornei on

information



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populations, with only Compass® and Commander® falling into a low-risk category (Figure 3). 7

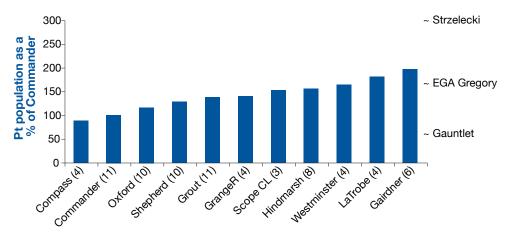


Figure 3: Comparison between barley varieties of P. thornei (Pt) population remaining, as a percentage of Commander (), 2009–13. Number of field trials in which the variety was evaluated is in parentheses. The positions of the wheat varieties on the right of the graph indicate best current estimate of comparison between these varieties for Pt build-up. Data generated are where barley and wheat have been grown within the same replicated trial or at least at the same trial site.

Crop varieties are rated for resistance and tolerance to RLN and results published each year at National Variety Trials Online. The mechanisms of resistance and tolerance are different and need to be treated as such.

Eradication of RLN from an individual paddock is highly unlikely, so effective long-term management is based on choosing options that limit RLN multiplication. This involves employing crop or varieties that have useful levels of P. thornei resistance and avoiding varieties that will cause large 'blow-outs' in P. thornei numbers.

8.3 Management

There are four key strategies for the management of RLN (Figure 4):

- Test soil for nematodes in a laboratory.
- Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.
- Choose tolerant varieties to maximise yields (GRDC: Crop variety guides). Tolerant varieties grow and yield well when RLN are present.
- Rotate with resistant crops to prevent increases in RLN (Table 1, Figure 4). When large populations of RLN are detected, you may need to grow at least two resistant crops consecutively to decrease populations. In addition, ensure that fertiliser is applied at the recommended rate so that the yield potential of tolerant varieties is achieved. 8

Know more. Grow more.

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B Burton, R Norton, R Daniel (2015) Root lesion nematodes importance, impact and management. GRDC Update Papers, 3 August 2015, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet, http://www.soilguality.org.au/factsheets/root-lesion-nematode-in-gueensland



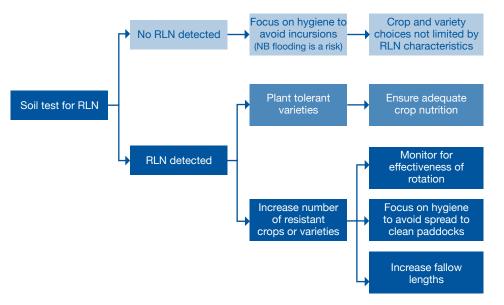


Figure 4: Root-lesion nematode management flow-chart.

Nematodes reduce yields in intolerant cultivars and reduce the amount of water available for plant growth. They also impose early stress, which reduces yield potential despite the availability of water and nutrients.

In the Southern Region, *P. thornei* at 10 nematodes/g soil can cause grain yield losses of 10–15% depending on seasonal conditions.

8.3.1 Crop rotation

The primary method of managing RLN populations is to focus on increasing the number of resistant crops in the rotation. Knowledge of the species of RLN present is critical, because crops that are resistant to *P. thornei* may be susceptible to *P. neglectus*. Key crops that are generally considered resistant or moderately resistant to *P. thornei* are sorghum, sunflower, maize, canola, canary seed, cotton, field peas and linseed.

Wheat, barley, chickpeas, faba beans, mungbeans and soybeans are generally susceptible, although the level of susceptibility may vary between varieties.

8.3.2 Resistance differences between commercial barley varieties

Resistance ratings to RLN have been available for many years; however, the development of high-throughput DNA analysis has enabled an increased amount of testing to compare RLN build-up between varieties under field conditions.

8.4 Symptoms and detection

Root-lesion nematodes are microscopic and cannot be seen with the naked eye in the soil or in plants. The most reliable way to confirm the presence of RLN is to have soil tested in a laboratory. Fee-for-service testing of soil offered by the PreDicta B root-disease testing service of the South Australian Research and Development Institute (SARDI) can determine levels of *P. thornei* and *P. neglectus* present. ⁹

Know more. Grow more.

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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



Soil testing can be conducted either by manual counting (under microscopes) or by DNA analysis (PreDicta B). Similar results are obtained by both methods with commercial sampling generally at depths of 0–15 or 0–30 cm. ¹⁰

Vertical distribution of *P. thornei* in soil is variable. Some paddocks have relatively uniform populations down to 30 cm or even 60 cm. Some will have highest *P. thornei* counts at 0–15 cm depth, whereas other paddocks will have *P. thornei* populations increasing at greater depths, e.g. 30–60 cm. Although detailed knowledge of the distribution may be helpful, most on-farm management decisions will be based on the presence or absence of *P. thornei* confirmed by sampling at 0–15 or 0–30 cm depth.

Signs of nematode infection in roots include dark lesions or poor root structure. The damaged roots are inefficient at taking up water and nutrients—particularly nitrogen (N), phosphorus (P) and zinc (Zn)—causing symptoms of nutrient deficiency and wilting in the plant shoots (Figure 5). Whereas intolerant wheat varieties may appear stunted, with yellowing of lower leaves and poor tillering, these symptoms may not be present in other susceptible crops such as barley and chickpeas. ¹¹



Figure 5: Aboveground symptoms of root-lesion nematode are often indistinct and difficult to identify. Affected plants (centre) may show poor vigour and they are often stunted, and cereals tiller poorly.

8.4.1 What is seen in the paddock?

Symptoms of RLN damage can easily be confused with nutritional deficiencies and/or moisture stress.

Damage from RLN is in the form of brown root lesions, but these can be difficult to see or can be caused by other organisms. Root systems are often compromised, with reduced branching, reduced quantities of root hairs and an inability to penetrate deeply into the soil profile. The RLN create an inefficient root system, which reduces the ability of the plant to access nutrients and soil water.

Visual aboveground damage from RLN is non-specific. Yellowing of lower leaves may be observed, together with reduced tillering and a reduction in crop biomass. Symptoms are more likely to be observed later in the season, particularly when the crop is reliant on moisture stored in the subsoil.

In the early stages of RLN infection, localised patches of poorly performing plants may be observed. Soil testing of these patches may help to confirm or eliminate RLN as a possible issue. In paddocks where previous wheat production has been uniform, a



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R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Managing-root-lesion-nematodes-how-important-are-crop-and-variety-choice

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



random soil-coring approach may be more suitable. Another useful indicator of RLN presence is low yield performance of RLN-intolerant varieties. 12

8.4.2 Belowground symptoms

Because aboveground symptoms of RLN damage are almost indistinguishable from other root diseases or nutrient constraints, it is necessary to examine plant roots for symptoms.

To inspect the root systems for diseases, they should be dug from the ground with a shovel. Do not pull 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.

In cereals, primary and secondary roots will show a general browning and discoloration. There will be fewer, shorter laterals branching from the main roots and a lack of root hairs (Figure 6). The root cortex (or outer root layer) will be damaged and it may disintegrate.

Visual diagnosis is difficult and can be confirmed only with laboratory testing or by using a PreDicta B soil test.



Figure 6: Symptoms of root-lesion nematode on roots include darkening of the cortex and lack of root hairs.

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R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Managing-root-lesion-nematodes-how-important-are-crop-and-variety-choice



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8.5 Nematodes and crown rot

The GRDC-funded Northern Grower Alliance has been involved in 22 field trials since 2007, in collaboration NSW Department of Primary Industries, evaluating the impact of crown rot on a range of winter-cereal crop types and varieties. ¹³

Over this time, awareness has increased about the distribution and importance of RLN, predominantly *P. thornei*, and its interaction with the expression of crown rot. This has raised the issue of the relative impact of crown rot and *P. thornei* on wheat relative to barley and which is the better rotation option if a moderate to high disease risk situation cannot be avoided. ¹⁴

8.6 Testing for root-lesion nematodes

Growers are advised to check the roots of the host crops if they suspect RLN infestations. Carefully dig up roots, then wash the soil from the roots of an infected plant and inspect for symptoms (as above). 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.

A DNA test, <u>PreDicta B</u>, is commercially available around Australia and growers should contact their state department of agriculture for advice. Grain producers can access PreDicta B via agronomists accredited by SARDI to interpret the results and provide advice on management options to reduce the risk of yield loss.

PreDicta B samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program.

Crop diagnosis is best achieved by sending samples of affected plants to your local plant pathology laboratory.

Postal address for PreDicta B samples: C/- SARDI RDTS, Locked Bag 100, Glen Osmond, SA 5064.

Courier address: SARDI Molecular Diagnostics Group Plant Research Centre, Gate 2B Hartley Grove, Urrbrae, SA 5064.



R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Managing-root-lesion-nematodes-how-important-are-crop-and-variety-choice

S Simpfendorfer, R Graham, G McMullen (2015) High crown rot risk—barley vs wheat. GRDC Update Papers, 1 March 2015, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/High-crown-rot-risk-barley-vs-wheat



SECTION 9

Diseases



GRDC: Current and potential costs from diseases of barley in Australia

Barley diseases cause an estimated current 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 the Southern Region, cereal cyst nematode, net blotch (spot form), leaf rust, net blotch (net form) and barley grass stripe rust 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 Southern Region

Disease	\$/ha	\$ million
Cereal cyst nematode	62.64	148
Net blotch, spot form	55.23	131
Leaf rust	30.49	72
Net blotch, net form	22.87	54
Barley grass stripe rust	22.73	54

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.
- Have a planned, in-crop fungicide regime.
- Conduct in-crop disease audits to determine the severity of the disease. This can be used as a tool to determine which crop is grown in which paddock the following year.
- Conduct in-fallow disease audits to determine the severity of the disease (e.g. crown rot, cereal cyst nematode, Rhizoctonia bare patch). This can also be used as a tool to determine which crop is grown in which paddock the following year.
- Send plant or stubble samples away for analysis to determine the pathogen or strain, or the severity of the disease.





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G Murray, JP Brennan (2009) The current and potential costs from diseases of barley in Australia. GRDC, http://www.grdc.com.au/~/media/CF32E282F9E241488125CD98A6567EB8.pdf

² UNE Sustainable Grains Production course notes.

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





GRDC: The current and potential costs from diseases of barley in **Australia**

GRDC Fact Sheets: Green bridge control is integral to pest and disease management

- Keep the farm free from weeds, which may carry over some diseases. This includes self-sown cereals over summer that may act as a green bridge.
- Rotate crops. 4

Disease epidemics develop when susceptible varieties are sown over wide areas in the presence of plentiful inoculum under favourable environmental conditions. The year 2010 provided the most favourable conditions for the development of foliar diseases for 12 years, and generated epidemics of yellow spot in wheat, and spot form of net blotch, leaf scald and leaf rust in barley. After several years of relatively low levels of these diseases, all of these factors contributing to epidemic development combined to initiate epidemics quite early in crop development. 5

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.

For more information on variety characteristics and reaction to diseases, see the NSW Department of Primary Industries (DPI) publication: Winter crop variety sowing guide 2015.

Causes of cereal diseases 9.1

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.

9.1.1 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.

9.1.2 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 of the cereals.

9.1.3 **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.





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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

G Platz (2011) Yellow spot in wheat; leaf rust and net blotch diseases in barley-lessons from 2010 for better management in 2011. GRDC Update Papers 19 April 2011, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/04/Yellow-spot-in-wheat-leaf-rust-and-net-blotch-diseases-inbarley-lessons-from-2010-for-better-management-in-2011



9.1.4 Nematodes

Nematodes are worm-like animals that cause various diseases in cereals. Most nematodes attack the plant roots or lower stems. An exception is the seed gall nematode, which causes cockles in wheat. Nematodes feeding on plants cause direct damage by reducing root area, damaging the transport mechanism, or, in the case of the seed gall nematode, by replacing the grain with galls full of nematodes. ⁶

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.

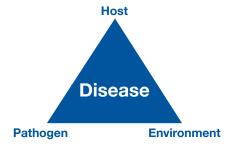


Figure 1: The disease triangle.

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, especially of summer crops, become more susceptible to *Pythium*, *Rhizoctonia* 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. ⁷

Information on the main diseases affecting wheat, including their control, is presented in Table 2.



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⁶ H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

⁷ UNE Sustainable Grains Production course notes.





Table 2: Barley disease guide

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).

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, barley grass and Star of Bethlehem	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 wheat, triticale and barley 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. Rainsplash	Disease is not of economic importance
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





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Disease	Organism	Symptoms	Occurrence	Inoculum source	Control
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



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9.3 Variety response

Barley varieties carry varying tolerance and resistance to diseases (Table 3).

Table 3: Barley variety disease ratings

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

	Leaf Net blotch		Powdery Leaf		BYDV	BYDV CCN	RLN resistance		BGSR	
	scald	Spot form	Net form	mildew	rust	- 515 v	resis.	P. neglectus	P.	<u> </u>
Malting barley										
Baudin	S-VS	MS-S	MR- MS#	VS	VS	MR	S	MR	-	R
Buloke(1)	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(1)	S	S-VS	MS	MR	MR#	MR-MS	R	MR	MR	R
Navigator(1)	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(1)	R#	S	MS-S	R	MR-MS	MR-MS	_	MR-MS	MR-MSp	R
Wimmera(1)	MS-S	S	MS-S	S	MR#	MR-MS	S	MR-MS	MR-MS	MR
Feed barley										
Capstan(1)	S	MS	MS-S	MR	MR-MS	S	R	_	_	MR-MS
Fathom(1)	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(D	S-VS	S-VS	MR	MR-MS#	MS-S	S	R	MR-MS	MR-MS	R
Keek	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(1)	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

9.4 Environmental factors

9.4.1 Cereal disease after drought

Drought reduces the breakdown of plant residues. This means that inoculum of some diseases does not decrease as quickly as expected, and will carry over for more than one growing season, such as occurs with crown rot, net blotches and leaf scald. 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.

For information, see the NSW DPI information sheet: Cereal diseases after drought. 8





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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



9.4.2 Cereal disease after flood 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.

Cereal diseases that need living plants over-season on volunteer (self-sown) crops. This is particularly so for rusts and mildews. Diseases such as yellow spot, net blotches and head blights survive on stubble. Crown rot and nematodes over-season in soil.

Problems are recognised by inspecting plants. Leaf and stem rusts produce visible pustules on leaves, whereas stripe rust survives as dormant mycelium, with spores not being produced until temperatures favour disease development.

The presence of leaf spots is recognised by the occurrence of fruiting bodies (pseudothecia) on straw and lesions on volunteers. Head blights produce fruiting bodies (perithecia) on straw, and crown rot survives mainly as mycelia in straw. Soilborne nematodes are detected through soil tests. ⁹

9.5 Management options

Management options for disease control include elimination of volunteers, if possible having a 4-week period that is totally host-free, crop rotation with non-hosts, growing resistant varieties, reduction of stubble, and 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. Timing and rate of application are more important than product selection. Stripe-rust ratings in variety guides are for adult plant response to the pathogen and may not accurately reflect seedling response. 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

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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

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

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 Foliar diseases

9.6.1 Rusts

Rusts are important diseases of barley and can cause severe crop damage in susceptible varieties when conditions are conducive. The rusts can, however, 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. The exotic pathogen barley stripe rust will cause severe losses in most varieties if it is introduced to Australia. ¹²

Plants facilitating the survival of rust fungi through the summer are known as the 'green bridge'. These are alternative hosts or volunteer cereals.

Rust diseases can be significantly reduced by removing this 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. See the University of Sydney's <u>Plant Breeding Institute (PBI) site</u> and their <u>publications</u> for more information.

Monitoring should start no later than Zadoks growth stage (GS) 32, the second node stage on the main stem, and continue to at least GS39, the flag-leaf stage. This is because the flag 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

Some areas of South Australia are very prone to barley leaf rust and infections can show up earlier than GS 32.

Agronomist's view

To keep up to date with rust incursions throughout the winter crop season, subscribe to the PBI <u>Cereal Rust Report</u>.



CropPro: Foliar diseases of barley





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¹² CropPro. Foliar diseases of barley. GRDC/State Government Victoria, http://www.croppro.com.au/cropdisease_manual/ch02s04.php

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



The PBI also offers a rust-testing service for growers and agronomists. For more details, see the Dispatch forms at: http://sydney.edu.au/agriculture/plant breeding institute/cereal rust/reports forms.shtml#df.

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 4 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; you can consult state agricultural department fact sheets, charts, websites and experts.
- When deciding whether a fungicide spray is needed, consider crop stage and potential yield loss.
- Select a recommended and cost-effective fungicide.
- For effective coverage, the use of the right spray equipment and nozzles is important.
- Read the label and wear protective gear; protect yourself and the environment.
- 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.
- If you suspect a severe disease outbreak, especially on resistant varieties, contact your state agricultural department.

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 that 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

Recommended fungicides for rusts

To keep up to date with the latest recommended fungicides for rusts, visit: <u>Australian Pesticides and Veterinary Medicines Authority</u>.

More information

GRDC Fact Sheets: Adult plant resistance



GRDC Update Papers: Stripe rust – prevention is generally best

GRDC Update Papers: Fungicide management of stript rust in wheat: up-front vs in-crop options





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9.6.2 What to look for

Leaf rust of barley

Pustules of leaf rust are small and circular, producing a mass of orange-brown powdery spores predominantly on the upper leaf surfaces (Figure 2). 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.



Figure 2: Leaf rust symptoms on barley leaf.

Stem rust of barley

The large pustules are oval to elongated, and are often surrounded by a characteristic torn margin (Figure 3). 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.



Figure 3: Stem rust symptoms on barley.

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 (Figure 4). 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. If barley stripe rust is suspected check the <u>Agriculture Victoria Cereal disease guide</u> for a resistance rating. It should be reported to Department of Primary Industries pathology staff.



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Figure 4: Barley grass stripe rust symptoms on barley.

9.6.3 Disease cycle

Leaf rust of barley

The primary source of inoculum for leaf rust is green volunteer barley plants that survive over summer. However, the 'Star of Bethlehem' (*Ornithogalum umbellatum*) weed (Figure 5) can also be a source of inoculum through teleospores, which are able to undergo a sexual reproductive cycle that produces a new generation of spores to re-infect barley.



Figure 5: Star of Bethlehem, a source of inoculum for leaf rust.

The existence of a sexual cycle means that new strains of rust can occur, thus increasing the chance of the rust overcoming current resistance. Currently the Star of Bethlehem weed occurs in South Australia, with isolated occurrences through the Victorian cropping zone. Development of leaf rust is most rapid during warm (15–20°C) moist (rain or dew) weather. Crops sown before May, when nights are still warm, are often more severely infected.



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Stem rust of barley

Stem rust survives the summer on volunteer wheat, barley, triticale and grasses, including common wheat grass and barley grass. Spores are spread from these hosts to the new crop by the wind. High humidity and heavy dew favour its development. It is most rapid at temperatures near 20°C and is markedly reduced by temperatures $\leq\!15^{\circ}\text{C}$ and $\geq\!40^{\circ}\text{C}$. 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.

9.6.4 Management of barley rusts

Resistant varieties

The most effective way to control the three rusts of barley is to grow varieties with resistance to each disease. It is important to note that these rusts are able to produce new races, which are capable of attacking varieties that were resistant when they were first released. To select varieties with resistance, it is essential to consult an updated Agriculture Victoria Cereal disease guide. By growing resistant varieties, the amount of disease in a crop and neighbouring crops is reduced, the chance of the rusts mutating, enabling them to attack previously resistant varieties is reduced, and the resistances currently available are better protected.

Cultural practices

It is important to remove the inoculum provided by self-sown barley over summer where possible. These rusts survive predominantly on summer volunteers, which provide significant inoculum loads if left unmanaged. Even small amounts of rust not destroyed in the autumn can multiply to cause serious yield losses if spring weather conditions are favourable for diseases. Use grazing or herbicides to remove green growth, especially during wet summers.

Seed treatment

Several seed treatments are registered for rust control in barley; however, efficacy varies between active ingredients, so it is strongly recommend that a cereal seed treatment guide, such as <u>PIRSA's Cereal seed treatments 2016</u>, be consulted.

Fungicides

A range of fertiliser and foliar applied fungicides is available that will give disease suppression of leaf rust in barley. Research has shown that the most effective suppression of leaf rust was achieved when foliar fungicides were applied early in epidemic. Additional applications may also be required where rust pressure is sustained during a wet spring. Fertiliser-applied fungicides can also provide suppression of barley leaf rust; however, their effectiveness is restricted to the seedling stages of crop development and additional application/s of foliar fungicide may be required.

Systiva® (from BASF) is being marketed as a seed-applied foliar fungicide.

Agronomist's view





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Figure 6: Scald of barley. Early water-soaked, grey-green symptoms compared with later straw-coloured lesions with a distinctive brown margin.

Scald of barley

Barley scald is caused by the fungus *Rhynchosporium secalis* and is common in Victorian barley crops in most seasons. Its severity varies between crops and seasons, but in general, it is more prevalent in high-rainfall areas. Field experiments have estimated grain yield losses due to scald to be 10–20% in susceptible varieties, and individual losses as high as 45% have been recorded.

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 ovate to irregular in shape (Figure 6). In severe infections, the disease may virtually cause defoliation by coalescing of the lesions (Figure 7). 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.



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Figure 7: Severe scald of barley: 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 8). 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 the spring.



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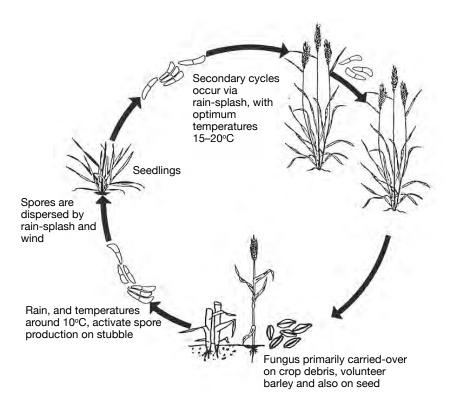


Figure 8: Disease cycle of barley scald.

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 2 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. The most recent example is the variety Hindmarsh®, which was initially resistant but is now susceptible to scald. It is important to check the <u>Agriculture Victoria Cereal disease guide</u> for the resistance status of varieties.
- Fungicides. A range of foliar fungicides is available that will provide suppression of scald. Experiments conducted during 2010 and 2011 showed that 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;



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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.

Net blotch

There are two forms of net blotch present in Australia. The net form of net blotch, caused by the fungus *Pyrenophora teres* f. *teres*, is currently less common in southeastern Australia because the majority of barley varieties are resistant, but it can be more damaging. The spot form of net blotch, 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. However, losses to spot form of net blotch are minimal in most cases.

Spot form of net blotch—what to look for

Symptoms are most commonly found on leaves, but occasionally on leaf sheaths. Symptoms develop as small circular or elliptical dark brown spots surrounded by a chlorotic zone of varying width (Figure 9). 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.



Figure 9: Typical symptoms of spot form of net blotch.

Net form of net blotch—what to look for

The net form of 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 (Figure 10).



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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.





Figure 10: Typical netting symptoms of net form of net blotch.

Disease cycle

The disease cycles for the two forms of net blotch differ, in that the net form can be carried over on seed, whereas the spot form is not seed-borne. Carryover of net form of net blotch occurs when humid conditions are present at crop maturity (Figure 11). Primary inoculum of both forms 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 (Figure 12), 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 \leq 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. Unlike the ascospores, conidia are wind-dispersed and therefore can travel considerable distances. 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





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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.

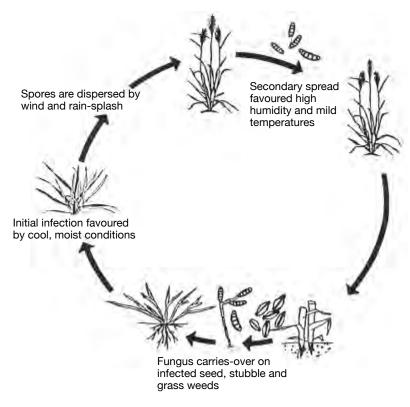


Figure 11: Disease cycle of net form of net blotch of barley.



Figure 12: 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 form generally ranging between 10% and 20%, and losses of >30% reported. Spot form of 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 form of 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. Consult the current <u>Agriculture</u>
<u>Victoria Cereal disease guide</u> when selecting varieties. The widespread use of



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varieties with resistance to net form of net blotch has effectively managed this important disease in Victoria for 20 years.

- 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 form
 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 the spot form of net blotch. Seed treatments containing the active ingredient thiram can reduce severity of net form of net blotch in seedlings. Seed treatments containing difenoconazole + metalaxyl can reduce the carryover of seed-borne net form of net blotch. Seedborne 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 increase 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 net form and/ or spot form of net blotch. Monitor barley crops and apply a registered fungicide if required. Research has shown that 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. 15

9.6.5 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. In the southern grain-growing region, the most common species are the oat aphid (*Rhopalosiphum padi*), the corn aphid (*R. maidis*) and rose grain aphid (*Metopolophium dirhodum*). Trials have found that the oat and rose grain aphids occur on wheat and barley and the corn aphid favours barley and is rarely found on wheat. ¹⁶





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¹⁵ CropPro. Foliar diseases of barley. GRDC/Government of Victoria, http://www.croppro.com.au/cropdisease manual/ch02s04.php

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



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.
- 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. ¹⁷
- 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 (Figure 13).



Figure 13: BYDV symptoms in barley. Note the yellowing of the leaf tip. (Photo. 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.

Research by the Victorian Department of Primary Industries Field Crops Pathology Group at Horsham in 1984 found that yield losses of 9–79% occurred when plants were infected early in the growing season (before the end of tillering) and losses of 69% may occur when plants are infected after tillering.

A trial conducted in the South East of South Australia by Trent Potter also investigated yield losses in wheat caused by BYDV. Losses varied from nil in 1990 and 2002 up to 40% in 2008. In other years, the yield losses were 10–20%. Even where large yield





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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



losses due to BYDV have occurred, trial results showed no difference in protein content between sprayed and untreated plots. ¹⁸

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 that you walk throughout the crop and pull up 10–20 plants from a range of locations. Inspect the crown, lower stem and leaves for aphids. In barley, check inside the unfurled leaf at the top of the tiller.

If plants average \geq 10 aphids per 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. ¹⁹

Predicting infection

The prevalence of BYDV depends on environmental conditions, host–pathogen dynamics and aphid populations.

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 southern 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. ²⁰

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. 21

Seed dressings

Seed dressings with imidacloprid have been shown to reduce aphid numbers in cereal crops at the early stage of growth when cereals are most susceptible to BYDV. Do not graze treated cereal crops within 9 weeks of sowing. In high-risk areas, a top-up spray (see below: *Insecticides*) is recommended at 6–8 weeks after sowing. ²²

Insecticides

Growers must work to prevent the spread of BYDV early after crop emergence, when plants are most vulnerable.



Australian Pesticides and Veterinary Medicines Authority





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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

¹⁹ 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

²⁰ 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

²¹ 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

² 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

information

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available from the

National Library of

Agriculture Victoria

Notes: Barley yellow

Agriculture Victoria:

Victorian winter crop

GRDC Fact Sheets:

Barley yellow dwarf

PIRSA: Cereal seed

MFMG: Wheat

agronomy trials

treatments

Australia.

dwarf virus

summary

virus

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February 2016

In high-risk areas, such as the long-season areas of South Australia and Victoria, which may have received high summer rainfall, growers can apply insecticides before aphids and/or BYDV symptoms are evident. This is considered a risk-based application. The insecticides will help to kill and repel the aphids, leading to increased yields, particularly when plants are young and small. Growers can utilise a range of approved insecticides to manage the aphids. As well as pyrethroids, other spray options can have less impact on non-target insects. These may suit farmers trying to incorporate integrated pest management into their system. Advice prior to spraying is essential.

Trial results have led to the recommendation that sprays are applied at 3 and 7 weeks after crop emergence. This is because BYDV symptoms are usually not obvious until 3 weeks after the aphids have fed on plants. These applications will enable aphid populations to be managed before the problem has been noticed and the aphids have spread even further.

Considerable BYDV spread can occur even when aphid numbers are low. Symptoms can be hard to see in winter. Consultation with an agronomist or crop pathologist is recommended.

In years conducive to aphid build-up, a follow-up insecticide application in spring, in addition to the early foliar or seed treatment strategies, may be required to limit feeding damage. The effect of late BYDV infection by itself is generally not sufficient to warrant spraying in spring, so the decision should be purely based on aphid pressure. ²³

BYDV resistance

There is some level of resistance to BYDV in cereals. The barley varieties Gairdner, Bass (b), Flinders(1) and Macquarie(1) contain the Yd2 gene, which gives moderate resistance to BYDV. 24

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 that this option is generally considered a poor choice over use of insecticides. Growers in the late-sown high-rainfall areas should note that late sowing might coincide with peak spring flights of aphids, resulting in more severe damage. 25

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. 26

Powdery mildew is currently under effective control in the Southern Region when treated seed or fertiliser is used and resistant cultivars are grown. However, care is

9.6.6 Powdery mildew

needed to maintain this situation to minimise the risk of the pathogen developing into a threat to the industry. 27

Grains Research & Development Corporation



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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 (Figure 14). These colonies produce windborne spores that spread the disease during the growing season (Figure 15).

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. ²⁸



Figure 14: 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. (Photo. Ryan Fowler, DAF Qld)



Know more. Grow more.

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GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat





Figure 15: A powdery mildew infection showing the black fruiting bodies (cleistothecia) that allow the disease to survive on stubbles.

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
- high N nutrition
- 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. ²⁹





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²⁹ GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat





Choose the best variety

The best way to minimise losses and slow or prevent the development of fungicide resistance is to plant the varieties that are more resistant and thereby minimise the need for foliar sprays.

However, the pathogen is capable of evolving and overcoming the resistance of some varieties. This is more likely if the disease is not controlled, because higher populations of the fungus will result in more mutations, which may lead to loss of resistance.³⁰

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 is particularly the case 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. ³¹

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 virulences 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.

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 Qol–DMI (quinone outside inhibitor–demethylation inhibitor) mix for the first foliar spray and a DMI for the second.

Fungicide resistance in the Southern Region

In Western Australia, 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 seed treatments, repeated use of the DMI fungicides tebuconazole, flutriafol and triadimenol as foliar sprays, and widespread use of varieties rated VS. ³² Similar changes are likely to occur in eastern Australia.



Australian Pesticides and Veterinary Medicines Authority





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GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat

³¹ GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat

GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat



Growers can significantly reduce the chances of this happening, or at least delay the occurrence, by avoiding the use of susceptible varieties, using effective fungicide treatments at seeding, and taking care over the use of foliar fungicides.

Growers should avoid using 'weaker' Group 3 DMI foliar fungicides (triadimefon, flutriafol, tebuconazole and triadimenol) for control of powdery mildew (Figure 16) and instead consider triazole fungicides such as epoxiconazole, prothioconazole, propiconazole or cyproconazole.

The Group 11 Qols such as azoxystrobin and pyraclostrobin can also be used in combination with triazoles. Experience in Europe shows that the Group 11 Qols can lose their effectiveness very quickly if used alone. ³³



Figure 16: Triazole resistance in powdery mildew means that 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. (Photo: Richard Oliver, Curtin University)

Agriculture Victoria

information

Notes: Wheat disease management in the Wimmera

9.6.7 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 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; leaves
 of newly infected wheat plants have broken yellow stripes that merge as the plant
 ages to be pale yellow streaks. In older leaves, yellowing is toward tips.





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GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat



- Barley is less severely affected than wheat and varieties differ in their susceptibility to infection.
- Barley leaves have necrotic flecks and pale green streaks with older leaves showing yellow along the length (Figure 17).
- Early infected wheat and barley plants are stunted with multiple tillers and have seed heads that contain shrivelled or no grain. 34



Figure 17: Symptoms of wheat streak mosaic virus in barley; flecks enlarge and form green to yellow

Disease management should involve eliminating the 'green bridge' by controlling:

- wheat volunteers between crops
- grass hosts growing on the borders of areas to be sown to wheat
- grasses in fallows

streaks. (Photo: DAFWA)

This means that any green plant material should be dead at least 2 weeks before sowing the next cereal crop. 35



GRDC: Wheat streak <u>virus</u>

GRDC Fact Sheets: Wheat curl mite

GRDC Update Papers: Cereal disease update net blotch, eyespot, wheat streak mosaic virus and white grain

GRDC: Protecting the Australian wheat industry for the Wheat streak mosaic virus

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MyCrop (2015) Diagnosing wheat streak mosaic virus. Department of Agriculture and Food, WA, https:// www.agric.wa.gov.au/mycrop/diagnosing-wheat-streak-mosaic-virus

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9.6.8 Barley stripe

Barley strip is a very rare fungal disease that is most often found in irrigated barley.

What to look for:

- Yellow stripes on the base of leaves extend, turn dark brown, and eventually die.
- Dying leaves tend to split and fray along the stripes leading to a shredded appearance (Figure 18).
- Symptoms occur on the second or third leaf of seedlings then each subsequent leaf.
- Infected plants are stunted and heads often fail to emerge or emerge twisted and brown. ³⁶



Figure 18: Symptoms of barley stripe: dying leaves tend to split and fray along the stripes. (Photo: DAFWA)

More information

DAFWA: Diagnosing barley stripe

<u>CropPro: Foliar diseases</u> of barley

VirginiaTech: Barley stripe

Agriculture Victoria:
Rusts of barley

9.7 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 1- or 2-year break from susceptible hosts. Break crops must be kept free of grass weeds to be effective. ³⁷

Barley can incur root and crown diseases, including:

- take-all
- crown rot
- Pythium
- Rhizoctonia
- · cereal-cyst nematode
- · root-lesion nematode
- common root rot

9.7.1 Diagnosing root diseases in your crop

Look at the distribution of symptomatic plants throughout the whole crop. To determine whether a fungal or nematode root disease is affecting a cereal crop, look for patchy areas of poor crop growth associated with localised disease build-up.



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MyCrop (2015) Diagnosing barley stripe. Department of Agriculture and Food WA, https://www.agric.wa.gov.au/mycrop/diagnosing-barley-stripe

³⁷ G Hollaway, M McLean, J Fanning (2015) Cereal disease guide. AG1160. Revised February 2015. DEDJTR Victoria, http://agriculture.vic.gov.au/ data/assets/pdf_file/0007/252664/Vic-Cereal-Disease-Guide-AG1160-Feb-2015-V2.pdf



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Soil Quality Fact Sheets: Take-all disease Next, carefully dig up samples of apparently diseased, as well as nearby healthy, plants. Thoroughly 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. If you are sending plant samples to a diagnostic laboratory, send plants that have not been washed. ³⁸

9.7.2 **Take-all**

Take-all is a soilborne disease of cereal crops and is most severe on cereal crops throughout southern Australia, in the high-rainfall areas of the agricultural region and areas closer to the coast. 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 that 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.

Roots of affected plants are dark brown to black through fungal invasion (Figure 19). 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. ³⁹

For images and detailed information on identifying cereal root and crown diseases, see the <u>GRDC Cereal root and crown diseases</u>: <u>Back Pocket Guide</u>.





GRDC (2014) Take-all. GRDC Media Centre, 26 June 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Take-all

³⁹ GRDC (2014) Take-all. GRDC Media Centre, 26 June 2014, http://grdc.com.au/Media-Centre/Hot-Topics/Take-all



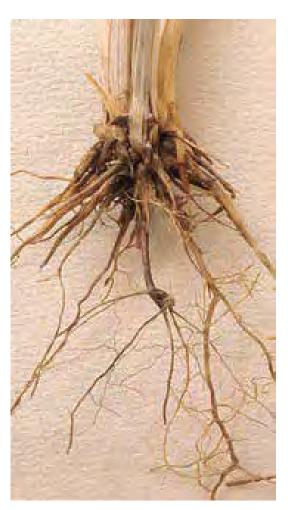


Figure 19: The sub-crown internode is the narrow portion of stem that links the old seed and primary root system to the crown and secondary root system just below the soil surface. (Source: GRDC Cereal and root and crown diseases: The Back Pocket Guide)

Control

No varieties of wheat and barley are available that 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 and they 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.



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NSW DPI: Winter crop variety sowing guide

GRDC: NVT Queensland wheat variety trial 2015

Research paper: Effect of rotation with barley and oats on crown rot of wheat in the northern wheat belt of New South Wales



GRDC Update Papers: Crown rot: be aware of the balancing act or the fall may be harder

GRDC Fact Sheets: Crown rot in cereals southern and western regions

GRDC video: Crown rot—it's all a balancing act

9.7.3 Crown rot

Crown rot is caused predominantly by the fungus *Fusarium pseudograminearum*. Crown rot affects wheat, barley and triticale. ⁴⁰ 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 clay soils.

Infection is favoured by high soil moisture in the 2 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. ⁴¹

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.

Damage caused by crown rot

The impact of crown rot on yield and quality is influenced by inoculum levels and available soil water. The primary factor increasing the impact of crown rot is moisture stress at grainfill, yet most management strategies focus heavily on combating inoculum, sometimes to the detriment of soil water storage or availability, which in turn exacerbates the effect of moisture stress.

Any management strategy that limits storage of soil water or creates constraints (e.g. nematodes or sodicity) that reduce the ability of roots to access water increases the probability of moisture stress during grainfill and therefore the severity of crown rot.



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.

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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

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NSW DPI: Northern

results. Autumn 2013.

Impact of sowing time

on crown rot in barley,

wheat - Walgett 2012

GRDC Ground Cover:

Seedborne fusarium

tests crown rot

grains region trial

bread and durum

(pp. 24-26)

strategies

information



February 2016

Pinched grain is observed at harvest. 42

Infection is characterised by a light honey-brown to dark brown discoloration of the base of infected tillers (Figure 20). 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. $^{\rm 43}$



Figure 20: Basal browning indicating crown rot infection.

Effect of sowing time

Earlier sowing within the recommended window of a given variety for a region generally brings the grainfill period forward to where the probability of moisture stress during grainfill is reduced. Earlier sowing may also increase the extent of root exploration at depth, which could provide greater access to deeper soil water later in the season, buffering against crown rot expression. This has been shown in NSW DPI research across seasons to reduce yield loss from crown rot. 44

Agronomists report anecdotal accounts of early sowing dates with long-season varieties resulting in greater soil moisture deficits during grainfill than later sowing dates. They say this combination has resulted in major yield loss and they reported a number of cases of this in 2013.

Crown rot phases

There are three distinct and separate phases of crown rot—survival, infection and expression. Management strategies can differentially affect these phases:



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UNE Sustainable Grains Production course notes.

More

extensionAUS: Crown rot in winter cereals Research paper:

Monitoring fusarium crown rot populations in spring wheat residues using quantitative real-

time polymerase chain

Research paper:

<u>Decomposition and</u> chemical composition of

reaction

information



February 2016

- Survival. The crown rot fungus survives as mycelium (cottony growth) inside
 winter cereal (wheat, barley, triticale and oats) 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 (Figure 21) 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. 45



Figure 21: 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.

<u>cereal straw</u> best indicator of

Managing crown rot requires a three-pronged attack:

1. Rotate crops.

Management

- 2. Observe plants for basal browning.
- 3. Test stubble and/or soil.

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Thesis: Crown
rot (Fusarium
pseudograminearum)
symptom development
and pathogen spread
in wheat genotypes
with varying disease
resistance

GRDC Update
Papers: Economics of
phosphorus and zinc
nutrition



Research paper: Effect of previous crops on crown rot infection and yield of wheat

More information

GRDC Ground Cover: Crown rot stubble avoidance lessens crown rot

NGA: GRDC Update
Papers—diseases

NGA Results and
Publications: Complete
summary



GRDC GCTV9: Crown rot & root lesion nematodes



GRDC Podcasts: Crown rot, root disease and WeedSmart



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 mustard, canola or faba beans.
- If growing cereals in crown-rot-affected paddocks, select types with lower risk of yield loss such as barley and some bread wheats. Avoid all durum varieties.
- 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.
- 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. faba bean and canola). 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. ⁴⁷

Inter-row sowing

Northern Grower Alliance (NGA) research shows:

- Inter-row sowing will reduce the level of crown rot incidence and severity (measured as inoculum in residues, not as whitehead expression), on average, by ~50%.
- Inter-row sowing provides increased disease-management benefit under conditions of low disease.
- Inter-row sowing will provide best benefit by incorporation into a crown rot diseasemanagement package based on sound crop rotation.

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

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GRDC Fact Sheets:
Stubble management—
strategies to manage
winter crop stubbles
without reaching for the
matches

GRDC Ground Cover: Stubble management still a burning question



GRDC Update Papers: Root lesion nematode and crown rot—double trouble burn is therefore preferable to an earlier, 'hotter' burn because it minimises the negative impacts on soil moisture storage while still reducing inoculum levels.

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.

9.7.4 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, look for patches or whole paddocks of very poor growth (Figure 22, left). Affected plants occur in patches where soil is wetter.

Seedlings are pale and stunted (Figure 22, middle). Older plants have fewer tillers and may rot and die. Roots are stunted, short and stubby with few laterals (Figure 22, right). Root tips often water-soaked and develop a soft yellow to light brown rot.



Figure 22: 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. ⁴⁹

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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





9.7.5 Rhizoctonia disease

Rhizoctonia root rot is an important disease of cereals in both the southern and western regions of the Australian grainbelt. This is especially the case in the lower rainfall zones and on lighter soils.

Yield losses in crops affected by bare patches can be >50%, and crops with uneven growth (Figure 23) may lose up to 20%. 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), and this can occur from emergence to crop maturity (Figure 24). The infection results in water and nutrient stress to the plant, because the roots have been compromised in their ability to translocate both moisture and nutrients. ⁵⁰

Severe seedling infection causes patches of poor crop growth from very small to several metres across (Figure 25). This can occur in cold or dry soils and conditions that restrict seminal root growth (e.g. compaction, lack of moisture, herbicide residues).

Warmer soil temperatures and adequate moisture are less conducive to the disease because crops escape seminal root infection, but crown roots can be affected by Rhizoctonia disease under low soil temperatures and poor nutrition, leading to uneven growth at tillering.



Figure 23: Aboveground symptoms of crop unevenness are seen when Rhizoctonia damages crown roots.



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GRDC (2016) Rhizoctonia. Southern Region. GRDC Tips and Tactics.





Figure 24: Symptoms of Rhizoctonia disease: left, healthy roots; middle, seedling severely infected; right, crown root fully infected. (Photos: Sjaan Davey)



Figure 25: Rhizoctonia infection of seminal roots results in distinct patches of poor growth. (Photo. Gupta Vadakattu)

Management options

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 of the disease. This complements the moisture- and N-conservation benefits of summer weed control.



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Crop choice and rotations

Cereals (especially barley) and grassy fallows promote the build-up of Rhizoctonia inoculum.

Crop rotation with a grass-free, non-cereal crop is one of the best available management strategies to reduce the impact of Rhizoctonia disease (Table 4). Trials across the lower rainfall cropping region of southern Australia have indicated that grassfree oilseeds, pulses, pasture legumes and fallow can result in significant reductions in Rhizoctonia inoculum in a cropping sequence.

Non-cereal crops can be infected by Rhizoctonia; however, most do not allow the buildup of inoculum. Lupins may be a less effective break crop and can suffer from yield damage in the presence of Rhizoctonia. The beneficial effect of rotation on reducing inoculum generally lasts for one cereal-crop season.

Fungicide treatments

Fungicide treatments need to be used as part of an integrated management strategy.

Responses in barley are greater than in wheat. Yield responses can vary between seasons, with the greatest responses occurring when spring rainfall is above average. In GRDC-funded trials in southern Australia and Western Australia, on average, seed treatments gave yield responses of 5% (0-18%) in wheat and barley.

Several products have been registered for liquid banding. GRDC-funded research showed that 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 roothealth responses across seasons.

Seed treatment combined with in-furrow application can provide intermediate benefit between seed treatment alone and split application.

Nitrogen

Nitrogen-deficient crops are more susceptible to Rhizoctonia disease. Intensive cropping with cereals and stubble retention result in very low levels of mineral-N over summer because 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

Therefore, ensure good N nutrition. 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. 51



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Table 4: Management of Rhizoctonia disease in cereal crops

Voor 1 oron (Sont New)	Summer (Dee April)	Sassan brook (April May)	Voor 2 oron (May August)
Year 1 crop (Sept-Nov) Check for inoculum build-up	Summer (Dec-April) Facilitate inoculum decline	Season break (April-May) Select appropriate crop	Year 2 crop (May-August) 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, especially if planning to sow cereals back on cereals 	 Select a non-cereal crop (e.g. canola or pulses) if you want 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



GRDC Update Papers: Rhizoctonia control improved by liquid banding of fungicides

Australian Pesticides and Veterinary Medicines Authority

MSFP: Management of soilborne Rhizoctonia disease risk in cropping systems

Identifying risk

<u>PreDicta B</u> 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'. 52

Biology

Rhizoctonia solani AG8 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 soil conditions including soil type, fertility, moisture, temperature and biological activity.

Although Rhizoctonia disease has often been a problem in low-fertility, sandy or calcareous soils of southern and Western Australia, with the increased adoption of conservation tillage and intensive cereal cropping, it now occurs in a wider range of environments from Western Australia to southern New South Wales.



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GRDC (2016) Rhizoctonia. Southern Region. GRDC Tips and Tactics.



The pathogen can infect, and cause spear tips in, a wide range of crops and weeds, but multiplies most on cereals and grasses. Of the cereals, oats are most tolerant followed by triticale, wheat and then barley. ⁵³, ⁵⁴

Key factors influencing occurrence and severity

Although the fungus is likely to be present in many soils, it does not necessarily cause disease symptoms. One reason for this is that beneficial soil microorganisms and high microbial activity have been shown to suppress the expression and reduce the level of disease.

The shift towards minimal tillage has resulted in conditions more favourable to the disease. Crown root infection late in the crop season results in the build-up of inoculum in cereal crops.

In cereals, *R. solani* AG8 inoculum builds up from sowing to maturity and generally peaks at crop maturity. Rain post-maturity of a crop and over the summer fallow causes a decline in inoculum (Figure 26).

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 pathogen inoculum to break down, with disease levels likely to remain stable if a host, or stubble, is present.

In cropping systems with stubble retention, suppressive activity has been shown to increase over 5–8 years. Biological suppression can provide complete control of Rhizoctonia disease and presently provides the best long-term control option. ⁵⁵

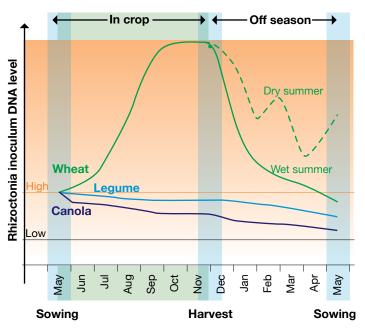


Figure 26: Rhizoctonia solani AG8 inoculum in soil builds up in-crop and declines during summer following rainfall under wheat. By comparison, inoculum levels decline in-crop under grass-free canola and legume crops.

9.7.6 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*. It survives from one season to the next



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GRDC (2016) Rhizoctonia. Southern Region. GRDC Tips and Tactics.

GRDC (2015) Rhizoctonia. Western Region. GRDC Tips and Tactics. https://www.grdc.com.au/~/media/Documents/Resources/Publications/Fact-sheets/TaTRhizoctoniaWestern.pdf

⁵⁵ GRDC (2016) Rhizoctonia. Southern Region. GRDC Tips and Tactics.

information

GRDC: Cereal root and

crown diseases. The

Back Pocket Guide



February 2016

through fungal spores, which remain in the top layer of the soil. The disease increases in severity with continuous wheat or 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 2 years is recommended.

9.7.7 **Smut**

Seed treatments provide cheap and effective control of bunt and smut diseases. Seed should be treated every year with a fungicide. 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 that 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.

What to look for

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 (Figure 27).



Figure 27: Covered smut on barley.





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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

Covered smut of barley can be effectively controlled by using fungicide seed treatments every year. Following infection, new seed should be obtained from a clean source. Resistant varieties are available. ⁵⁶

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 viceversa. Because of the widespread and regular use of seed treatments, loose smut of barley is not common in Victoria.

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 (Figure 28). Initially, the spores are loosely held by a thick membrane, which soon breaks, releasing the spores onto other heads. Finally, all that remains are 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.





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G Hollaway (2012) Bunts and smuts of cereals. AG1257 (updated July 2013). DEDJTR Victoria, <a href="http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/bunts-and-smuts-of-cereals





Figure 28: 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.

Control

Using systemic seed treatments every year will effectively control this disease. Following a loose smut outbreak in a crop, new clean seed should be sourced. ⁵⁷

Loose smut was observed in Hindmarsh barley crops despite use of seed treatment. Tests by Dr Wallwork (SARDI) showed that products with triadimenol, flutriafol, tebuconazole and ipconazole may not provide total control. The new SDHI 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 is likely to be similar to Hindmarsh. 58



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⁵⁷ G Hollaway (2012) Bunts and smuts of cereals. AG1257 (updated July 2013). DEDJTR Victoria, <a href="http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/bunts-and-smuts-of-cereals/bunts-and-smuts-and-smuts-of-cereals/bunts-and-smuts-of-cereals/bunts-and-smuts

G Hollaway, M McLean, J Fanning (2015) Cereal disease guide. DEDJTR Victoria, http://agriculture.vic.gov.au/data/assets/pdf file/0007/252664/Vic-Cereal-Disease-Guide-AG1160-Feb-2015-V2.pdf



SECTION 10

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 that 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

The concept of canopy management has been primarily developed in Europe and New Zealand—both different production environments from those typically found in most grain-producing regions of Australia.

Canopy management includes a range of crop-management tools for crop growth and development, to maintain canopy size and duration, thereby optimising photosynthetic capacity and grain production. One of the main tools available to growers to manage the crop canopy is the rate and timing of applied fertiliser nitrogen (N). ²

Results from the Southern Region have shown potential for the use of canopy management, especially in areas with high yield potential and therefore higher N inputs. At Inverleigh in Victoria, June-sown Gairdner showed a significant yield advantage when N application was timed at stem elongation (Zadoks growth stage, GS31–33) over N applied in the seedbed. ³

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. ⁴

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

N Poole (2005) Cereal growth stages. GRDC, http://www.grdc.com.au/uploads/documents/GRDC%20 Cereal%20Growth%20Stages%20Guide1.pdf

- SFS (2007) Defining guidelines for canopy management in barley for the different climatic regions of Australia—June sown Gairdner—Inverleigh, Vic. Crop Agronomy Trials. Southern Farming Systems/Online Farm Trials GRDC, http://www.farmtrials.com.au/view_attachment.php?trial_attachment_id=5118
- N Poole (2005) Cereal growth stages. GRDC, http://www.grdc.com.au/uploads/documents/GRDC%20 Cereal%20Growth%20Stages%20Guide1.pdf



BCG: Barley canopy management trial—Mallee

GRDC: Disease management and crop canopies

SFS: Crop agronomy trials—June sown Gairdner, Inverleigh, Vic.

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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





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 seasondependent. 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 aboveaverage 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. 5

10.1.2 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 by enabling increased winter stocking rates and generating income from forage and grain. Typically, these crops are earlier sown, longer season varieties that provide greater DM production for grazing. Research has shown that 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 DM removal without compromising grain production. ⁶

10.1.3 Key stages for disease control and canopy management

The optimum timing for foliar-applied fungicides in cereals is from the start of stem elongation to ear emergence (GS30-59). In barley, the second-last leaf formed is the key leaf. This is the leaf below the flag and is termed flag minus 1 (flag -1). This leaf appears at approximately the third-node stage (GS33). This period coincides with the emergence of the four most important leaves in the crop and the ear.



GRDC Update Papers: Grazing wheat and barley-impacts on crop management, lodging and grain yield





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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

GRDC (2102) grazing wheat and barley - impacts on crop canopy management. GRDC Update Papers, 23 March 2012), http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Grazingwheat-and-barley-impacts-on-crop-canopy-management-lodging-and-grain-yield







The optimum time for spraying a fungicide to protect a leaf is at full emergence. Leaves not emerged at the time of application will not be properly protected. Leaves will usually be free from foliar disease on emergence. The time between when the disease spores land on the leaf and when an infection point is visible is called the latent period or latent phase. This period is temperature-driven and differs between diseases. It can be as short as 7 days for diseases such as powdery mildew. 7

It was common 5-10 years ago to make decisions on fungicide applications for foliar disease based on thresholds of infection. These thresholds varied from 1% to 5% of plants infected. However, growers and advisers found that, in the paddock, it was difficult to calculate when this disease threshold had been reached, not least because of the sporadic nature of the initial foci of the disease. In addition, by the time growers realised that the threshold had been reached and carried out the spray operation, the crops were badly infected. When crops that are badly infected with stripe rust are treated with fungicides, the control is poor because fungicides work better as protectants than as curatives.

Because the flag leaf is less important in barley than in wheat, it is far more difficult to pinpoint an optimal timing window for fungicide application in barley. In addition, most of the popular varieties such as Gairdner have some disease weaknesses. Therefore, growers are advised to monitor from late tillering (GS25) for the presence of disease on the older leaves. Consider application based on propiconazole (Tilt®, Bumper®) where net blotch and/or scald are evident on newer leaves at GS30, or triadimefon for mildew.

Barley requires careful monitoring, and its lower leaves, which emerge earlier than in wheat, are more important to the plant than are 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
- Two-spray programs increase the likelihood of fungicide rate reduction with each spray. In wheat, fungicide activity against rusts is very effective at low rates; however, the existing fungicides do not control barley diseases as effectively at equally low rates.
- Barley often suffers from wet-weather diseases early in the season, but then is subject to drier/warmer weather diseases later in the season, again making it more difficult to target a single spray program under diverse disease pressure.



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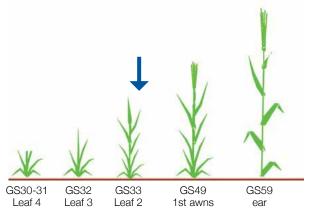
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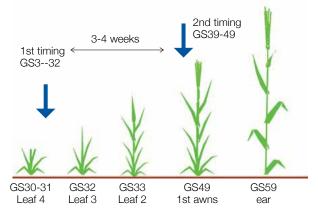
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N Poole (2005) Cereal growth stages. Grains Research and Development Corporation, http://www.grdc. com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf



Less easy to adopt single spray in Barley - however 1 spray best targeted at leaf 2 emergence (F-1) GS 33-37

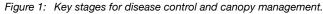






GRDC Driving Agronomy Podcasts: Disease management and crop canopies

When disease pressure is high from GS30 there are 2 focal points for Barley



10.2 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 plantstored 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®) act on later stages.

Plant growth regulators are reported to have a yield-enhancement effect by improving the proportion of crop DM 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



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highly variable, with responses ranging from -40% to +2%, depending on product choice, application time, crop or variety, and growing-season conditions. 8

In Australia, PGR availability for barley growers is limited to ethephon. 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. Whereas a great deal of resource has been devoted to optimising crophusbandry strategies to minimise lodging, 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, then 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. 9

Moddus® (trinexapac-ethyl at 250 g/L) is used by cereal growers in several countries including New Zealand, the UK and Germany to reduce the incidence and severity of lodging and optimise the yield and quality of high-yielding wheat, barley and oat crops. Moddus® Evo is an enhanced dispersion-concentrate formulation developed to provide greater formulation stability and more effective uptake in the plant. With improved mixing characteristics and the potential to provide better consistency of performance, Moddus® Evo is registered with APVMA for Australian cereals.

In 2011 and 2012, NSW DPI conducted trails on Moddus® to investigate the capacity of PGRs to reduce lodging in Commander barley, a high-yielding variety with poor straw strength. In both seasons, Commander and Oxford, a high-yielding variety with good straw strength, were grown at a target plant population of 120 plants/m² with four treatments of: nil PGR, Cycocel® (0.2 L/ha), Moddus® (1.0 L/ha) and a combination of Cycocel® + Moddus® (0.2 + 1.0 L/ha). PGRs were applied in each season during stem elongation (GS31) at a water rate of 100 L/ha. In 2011, sites were established at Tamworth and Spring Ridge, and in 2012, sites were at Moree and Breeza. 10

Results from 2011 showed that although the Tamworth site had lower lodging than Spring Ridge, the trends were similar (Table 1). The lodging severity for Commander was approximately 3 times that observed for Oxford(b, again highlighting the importance of variety selection in lodging management. The combination of Cycocel® and Moddus® was the most effective PGR treatment for reducing the severity of lodging compared with the control treatment (nil PGR).

Table 1: Lodging scores (scale 0-9, where 0 is standing and 9 is flat on the ground) at harvest for Spring Ridge and Tamworth sites in 2011

PGR treatment	Spring l	Ridge	Tamworth			
	Commander()	Oxford(1)	Commander(b	Oxford(1)		
Nil PGR	7.2	3.0	3.0	1.0		
Cycocel®	6.2	1.8	2.0	0.2		
Moddus®	5.3	1.8	2.0	0.0		
Cycocel® + Moddus®	4.6	1.9	1.8	0.0		

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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-thenorthern-grains-region-of-NSW

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- $\underline{\textbf{Development/GRDC-Update-Papers/2013/03/Moddus-Evo-Controlling-plant-growth-for-reduced-lodging-growth-for-reduced-lodging-growth-for-reduced-lodging-growth-grow$ and-improved-vields

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-thenorthern-grains-region-of-NSW



The ability of PGRs to reduce the severity of lodging appears related to their capacity to restrict plant height (Figures 2a and 3a). At Spring Ridge (2011) and Moree (2012), the Cycocel® + Moddus® treatment was the most effective at reducing plant height. As a single product, Moddus® restricted plant height more than Cycocel® at both sites. There was a large difference in height reduction at the two sites, with maximum height reduction being 7 cm at Spring Ridge in 2011 and 34 cm at Moree in 2012. At Spring Ridge, the treatments containing Moddus® had no impact on yield compared with the nil treatment, whereas the Cycocel® treatment significantly increased the yield of Commander by 8% compared with the nil treatment. The large reduction in plant height at Moree for the Moddus® and Cycocel® + Moddus® treatments resulted in a significant reduction in yield of 8% and 13%, respectively.

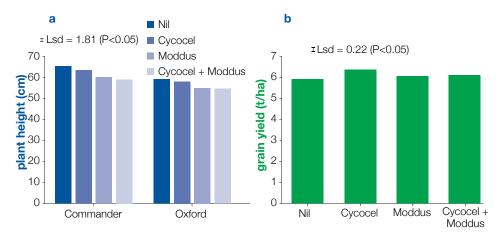


Figure 2: Effect of three PGR treatments on plant height and grain yield of Commander compared with a nil-PGR control at Spring Ridge in 2011.

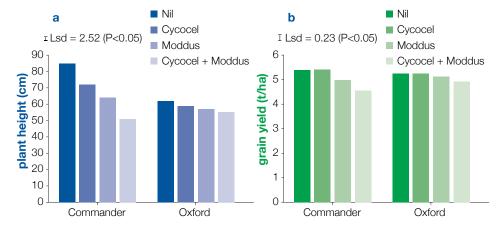


Figure 3: Effect of three PGR treatments on grain yield and plant height of Commander (1) and Oxford compared with a nil-PGR control at Moree in 2012.

In 2008, a trial at the Tamworth Agricultural Institute found a significant yield increase with early (GS25) applications of a PGR combination of Moddus® and Cycocel® in the absence of lodging for wheat (EGA Gregory(1) and durum EGA Bellaroi(1)), whereas no effect was found in Gairdner (b or Fleet (b barley. Later application resulted in no significant differences compared with the control.

Between 2004 and 2011, field trials with Moddus® were run across Australia by Syngenta, the manufacturer of Moddus®, 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® application on plant growth, stem strength, stem-wall thickness, lodging, lodging score and yield, as well as grain-quality

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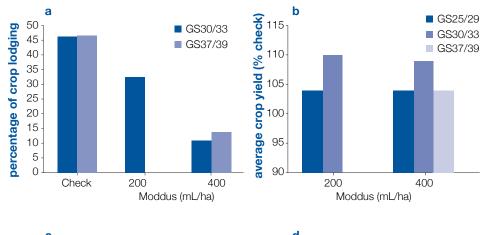
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measurements (Figure 6). Several rates of Moddus® Evo were assessed for reduction of lodging and enhancement of yield in barley. Moddus® Evo applied at rates of 300 or 400 mL/ha was consistently found to improve yields and reduce barley lodging (Figure 4a, b). The optimal growth stage for Moddus® 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® at GS37–39, growth compensation was reduced (Figure 4c). When conditions were favourable for bounce-back, the second application resulted in significant yield improvements. The results in Figure 6*d* 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. ¹¹



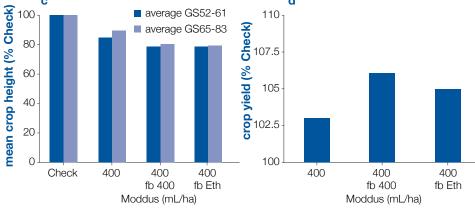


Figure 4: (a) Effect of Moddus® concentration on lodging when applied at early and late stem elongation in barley crops; data are a summary of multiple trials. (b) Effect of concentration and timing of Moddus® applications on barley yields, data are percentage improvement from untreated. Applications 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® on (c) barley stem heights and (d) barley yields when conditions favour compensatory growth following initial application.

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.



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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



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 that Moddus® Evo be applied only to healthy growing crops with optimum yield potential.

According to Syngenta, continuing research is aimed at developing a greater understanding of the factors that allow Moddus® Evo to improve cereal yields in the absence of lodging. Areas under investigation include:

- Survival and development of secondary tillers in high-biomass crops. Can the use
 of Moddus® Evo open the canopy, allowing the full development of secondary tillers
 in high-biomass crops with good soil moisture reserves?
- Enhanced root development. Research suggests that plants treated with Moddus® develop larger root systems. Larger root systems may allow plants to access greater soil moisture and nutritional reserves through the later stages of crop development.
- Redistribution of carbohydrates. Structural carbohydrates are converted to watersoluble forms to enhance crop yields under dry spring conditions. Preliminary results indicate that Moddus[®] has a significant effect on the concentration of WSC in wheat and barley.
- Frost damage reduction. The use of Moddus® Evo has been shown to delay
 midseason crop development by ~7–10 days. Although treated crops 'catch up'
 and do not incur a harvest-time penalty, on average, this initial delay results in later
 flowering and grain-filling in less frost-prone conditions.
- Barley head loss. Dramatic yield improvements were observed with certain barley varieties treated with Moddus® Evo due to head retention in conditions favourable to head loss. Further evaluation into the benefits of Moddus® Evo in reducing head loss in susceptible barley varieties is under way.

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. ¹²

10.2.1 Variety-specific research from the northern region

Commander is grown on heavier soils in the south and lodges, but not to the degree in the north. Growth regulators and defoliants aren't used in the south.

Agronomist's view

 $\frac{https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators}{Plant-growth-regulators}$

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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-vields







Commander is a malting barley variety that is gaining popularity with growers throughout the northern grains region. One of the major limitations to the further adoption of Commander is its susceptibility to lodging. Apart from being difficult to harvest, lodged crops can have limited grain yield by up to 40% and reduce grain quality.

NSW DPI trials investigating lodging management options for Commander were conducted at Spring Ridge and Tamworth between 2008 and 2011. These options included:

- Varying plant population. This was found to be an effective and easy way to reduce lodging severity. Reducing plant populations from 120 to 80 plants/m² reduced lodging severity by up to 32% in some trials, but further reduction in populations can also significantly reduce yield potential.
- Defoliation. When implemented just prior to stem elongation, defoliation has been shown to reduce lodging severity (by 8–35%) and the area affected by lodging (by 15–45%). However, it must occur prior to stem elongation to avoid yield penalties. Therefore, other methods are preferred.
- Potassium application.
- PGR application. In general, PGRs have resulted in reductions in lodging severity, primarily by reducing plant height by 5–12 cm. In some cases, unexpected yield benefits have occurred, with yield increases of 0.4–0.9 t/ha observed with PGR application relative to no PGR in the absence of lodging.

Owing to the strong susceptibility of Commander() to lodging, the combination of appropriate plant populations, defoliation and PGR has been shown to give the greatest reductions in lodging severity.

Trials have shown that some effective management options are available to growers to minimise lodging in Commander. The best lodging management practices are:

- Establish plant populations of ~80–100 plants/m². Higher plant population may be targeted in high-yielding situations, but other lodging-management practices will also need to be implemented.
- Defoliation through grazing can be used to minimise lodging. The closer to stem elongation that defoliation occurs, the more effectively the lodging risk is reduced.
- Avoid paddocks with excessively high soil N at sowing and, if possible, delay the application of N until stem elongation, when yield can still be increased without driving excessive grain protein concentration.
- PGRs do have the potential to reduce lodging through reduced plant height. A
 combination of PGR products offers the greatest reduction in lodging severity.
- In situations of high lodging risk, a combination of management practices may be required.

Similar management options for Commander and Oxford barley were investigated in NSW DPI trials at Bellata, Spring Ridge and Tamworth in 2011 (Figure 5). Oxford is a lodging-resistant variety.



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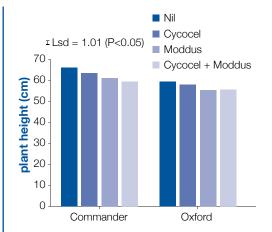


Figure 5: Effect of four PGR treatments on plant height of Commander ($^{\parallel}$ and Oxford ($^{\parallel}$ at Spring Ridge 2011.

Restricting the size of the crop canopy or DM production, like restricting plant height, was effective in reducing the severity of lodging. Defoliation and plant population were the most effective management strategies for restricting the DM production at anthesis (GS61) and maturity (GS99). On average across sites, defoliation reduced DM yield at anthesis by 5–9%; however, these reductions in DM yield by maturity were negligible. By contrast, populations of 60 and 80 plants/ m^2 maintained significantly lower DM yields than a population of 120 plants/ m^2 at both anthesis and maturity (Figure 6).

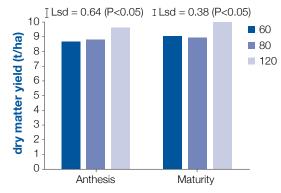


Figure 6: Dry matter yield for populations of 60, 80 and 120 plants/m² at anthesis and maturity. In summary, this trial found that choosing a variety that is less susceptible to lodging is the most effective management option for reducing losses from, and severity of, lodging. Where a variety susceptible to lodging (such as Commander(b) is grown, defoliation prior to stem elongation can reduce the severity of lodging and limit canopy size at anthesis. It is essential that defoliation does not occur beyond stem elongation (GS31) because significant yield penalties could be expected. Maintaining plant populations at ~80 plants/m² enabled DM yield to be restricted throughout the growing season, without significantly limiting yield. Of the PGR treatments, the combination Cycocel® + Moddus® reduced the severity of lodging to the greatest degree.

To read more about the results, go to: <u>NSW DPI: Northern grains region trial results—autumn 2012.</u>

A further trial on lodging management of Commander was conducted in 2012 by NSW DPI at sites in Breeza, Gurley and Moree (Table 2). In all trials, PGR treatments were shown to reduce lodging to some degree, most likely a function of the reduced plant height obtained from PGR applications. Yield responses to PGR application ranged from –13% to +16% for Commander and Oxford compared with the untreated control. Commander was usually more responsive to application of PGRs than Oxford . Of the PGR treatments, the combined Cycocel® + Moddus® treatment resulted in the

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most consistent reduction in plant height and greatest responses in grain yield, whether negative or positive.

These results highlight the variability in responses to PGR application, which makes it difficult to predict the economic benefit of using PGRs within cropping systems.

Table 2: Lodging scores (scale 0–9, where 0 is standing and 9 is flat on the ground) at harvest for the Moree and Breeza sites

Minus and plus relate to defoliation treatments

PGR	Moree				Breeza			
Treatment	Commander(b		Oxford(D		Commander(b		Oxford(b	
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus
Nil	3.4	1.9	0.0	0.0	8.5	6.5	3.5	3.3
Cycocel®	2.2	1.5	0.0	0.0	7.5	5.3	3.0	3.0
Moddus [®]	0.0	1.0	0.0	0.0	-	-	-	-
Cycocel® + Moddus®	0.0	0.0	0.0	0.0	4.8	4.3	2.0	1.5

The much greater severity of lodging at Breeza than Moree was ostensibly due to irrigated conditions at Breeza. A dry finish to the season ensured that lodging of Commander() remained minimal at Moree. To read more about this trial, go to: NSW
<a href="DPI: Northern grains region trial results—autumn 2012.

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SECTION 11

Crop dessication/spray out

Not applicable for this crop.



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SECTION 12

Harvest

In southern Australia, 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. Note that growers should not apply glyphosate or paraquat to malting barley varieties prior to harvest for either weed control or desiccation; it may result in reduced malting barley germination potential and maximum residue limit violations. 1,2

12.1 Header settings

Suggested header-setting adjustments for barley are:

- drum speed (rpm): conventional, 700–1000; rotary, 700–1000
- concave clearance (mm): front, 8; rear, 3
- fan speed: high

Harvest and handling are particularly important for malting barley because maintaining germination >95% is vital. 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: the initial header settings should have the concave set one notch wider than for wheat. 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. ³



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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

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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



12.2 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, you should check after beginning harvest to determine any harvest loss. It is recommended that a minimum of 10 counts be taken and averaged. 4,5

12.3 Wet 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. ⁶

Barley is physiologically mature at 30–50% moisture, which is well before it is ripe enough to harvest mechanically. 7

When ripe, winter cereals are easy to thresh, and harvest can begin at moisture content as high as 20%, although generally very little is harvested at >18% moisture. If harvested at >12.5% moisture, access to an aeration or drying facility is necessary. (For more information on storing barley, see GrowNotes Barley South, Section 13. Storage.) 8

12.3.1 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, methods to improve harvesting efficiency (chaser and mother bins), and the use of 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 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 costeffective option.

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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

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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



- Grain bags are an alternative means of keeping the grain away from the header during harvest through short-term storage in the paddock.
- With good carriers, it may be unnecessary to own enough trucks to keep up with high-capacity headers.

Delayed harvest due to wet weather can result in yield losses and downgrades in grain quality, which vary significantly between cereal varieties. Varietal differences in yield loss with delayed harvest can exceed 1.5 t/ha. If growers know which varieties are most susceptible to wet weather, they can make more informed decisions about prioritising harvest by variety.

12.3.2 Pre-harvest weather damage on barley varieties

In southern Australia, rainfall and strong winds are not uncommon around harvest time. In 2013, winds were prevalent, resulting in widespread reports of awn and head loss in some barley varieties. The ability of current commercial varieties to tolerate these conditions has been assessed in field trials at Turretfield and Moyhall, South Australia, during 2012 and 2013. Up to 24 varieties were harvested at two dates, beginning at physiological maturity and again more than 30 days later after significant rainfall and wind events that were conducive to head loss and quality downgrading. Lodging and head loss were measured at each harvest date and physical tests were conducted on grain samples from each plot.

Yield loss from delaying harvest has been most prevalent in Sloop SA(b, a variety known to have poor head retention. In some trials, it lost up to 180 heads/m², resulting in grain yield losses of >2 t/ha between harvest dates (Figure 1).

Newer barley releases have not been as susceptible as Sloop SA® to head loss. Of the newer releases, Oxford® did not incur significant yield losses from a delay in harvest across all three sites—seasons. GrangeR® and Bass® also demonstrated good head retention with minimal yield losses.

Hindmarsh® and LaTrobe® have both displayed superior straw strength and reduced lodging compared with other varieties such as Keel, Skipper, and Fleet® when harvest is delayed. However, their improved straw strength has not necessarily translated to improved head retention, with both Hindmarsh® and LaTrobe® recording large yield losses from a delay in harvest at more than one site—season, suggesting that they should be harvested early within a program along with other varieties more prone to head loss.

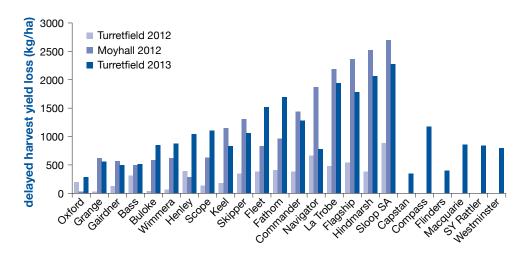


Figure 7: Yield loss (kg/ha) of current barley varieties between early and delayed harvest at Turretfield in 2012 and 2013 and Moyhall in 2012. Values of l.s.d. (P = 0.05) are 225, 395, and 450 kg/ha, respectively.



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⁹ A. Polkinghorne (2011) Cost effect harvest and logistics. GRDC Update Paper.



Factors other than wind conditions can contribute to head loss. These include disease, plant stress and changes in environmental conditions coinciding with the development period for a variety (maturity). Varieties were harvested as close to maturity as possible in these trials and plots were sprayed with fungicide. Leaf rust and spot form of net blotch in commercial paddocks may have contributed to a weakening of the plant structure and resulted in greater head loss than reported here. Fungicide trials have shown that a late spray of fungicide to protect against leaf rust significantly reduces lodging and head loss in the barley varieties that are most susceptible to disease. ¹⁰

12.4 Fire prevention

Grain growers must take precautions during the harvest season when operating machinery in extreme fire conditions. They should take all possible measures to minimise the risk of fire. Fires are regularly experienced during harvest in stubble as well as standing crops. The main cause is hot machinery combining 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. ¹¹

12.4.1 Using machinery

To prevent machinery fires, it is imperative that all headers, chaser bins, tractors and augers be regularly cleaned and maintained. All machinery and vehicles must have an effective spark arrester fitted to the exhaust system to prevent fires. To prevent overheating of tractors, motorcycles, off-road vehicles and other mechanical equipment, all machinery needs to be properly 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 this equipment outdoors. Tips on machinery include:

- 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 on to 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 onboard ignitions. ¹²

Downloaded the <u>Farm FireWise Checklist and Action Plan</u>, or you can request one through your local Fire Control Centre.

12.4.2 Steps to preventing header fires

With research showing that 12 harvesters, on average, are burnt to the ground every year in Australia (Figure 2), agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses.

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K Porker, R Wheeler (2014) Getting the best from barley; agronomy and management. GRDC Update Papers, 25 February 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Getting-the-best-from-barley-agronomy-and-management

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

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





Figure 8: Keeping headers clean can reduce the risk of fire. (Photo: Rebecca Thyer) Key points:

- Most harvester fires start in the engine or engine bay.
- Others are caused by failed bearings, brakes and electricals and rock strikes.
- Regular removal of flammable material from the engine bay is urged. ¹³

12.5 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, GrainCorp reports all protein figures at 0% moisture basis. Feedlots generally use the 'as-is' figure.

Growers should check receival standards with <u>GrainCorp</u> or their local grain merchant. Updated specifications are usually available from July each season, with all relevant information. Other purchasers of barley grain may use different specifications. ¹⁴

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.

GrainCorp provides a grower harvest information kit, including local contacts, contract options, warehousing conditions, grain-protection strategies and more. ¹⁵

Download the latest barley receival standards from the GTA website.

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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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More

GRDC Webinars:

Beginner's guide to

harvest weed seed

control

information



February 2016

FAQ 12.6 Harvest weed-seed control

Targeting weed seeds at harvest is a pre-emptive action against problematic populations of annual weeds. Our 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/m²) can therefore be reduced to a very modest one (<100 seed/m²) 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 three decades target the weed-seed-bearing chaff fraction during harvest. 16

Intercepting annual weed seed 12.6.1

In Western Australia, where high frequencies of herbicide-resistant annual weed populations have been driving farming practices for the last decade, techniques targeting weed seeds during harvest have been widely adopted, and these techniques are now being adopted in the southern states. At crop harvest, much of the total seed production for the dominant weed species is retained above harvester cutting height (Table 1). Additionally, for some of these species such as wild radish, high levels of seed are maintained over much of the harvest period (Figure 3). Therefore, the collection and management of the weed-seed-bearing chaff fraction can result in significant reductions in population densities of annual weeds.

Table 3: Proportion of total weed-seed production retained above a low harvest cutting height (15

Species	Seed retention above 15 cm (%)
Annual ryegrass	88
Wild radish	99
Brome grass	73
Wild oats	85

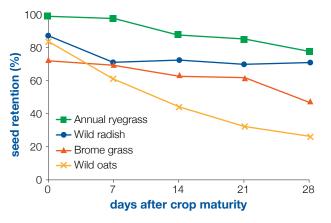


Figure 9: Seed retention above a harvest height of 15 cm over the first 4 weeks of harvest for the major crop weeds of Western Australian wheat crops.

Lower in-crop weed densities are easier to manage and their potential development as herbicide-resistant populations is dramatically reduced. Western Australian farmers





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M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www. grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control





IWM in Australian cropping systems: Section 4. Tactics

have driven the development of several systems now available that reduce inputs of annual ryegrass, wild radish, wild oats and brome grass into the seedbank. The adoption of these systems has been critical for the continuation of intensive cropping systems. 17

A key strategy for all harvest weed-seed control operations is to maximise the percentage of weed seeds entering the header. This means harvesting as early as possible before weed seed is shed, and harvesting as low as is practical (e.g. 'beer-can' height).

Burning of narrow windrow 12.6.2

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 (Figures 4 and 5) is achieved by attaching chutes to the rear of the harvester to concentrate the straw and chaff residues as they exit the harvester. This concentration of residue increases the seeddestruction 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. 18

Note that narrow windrow burning is not generally recommended in barley because of the bulkier canopy posing a greater risk of fire escape to the rest of the paddock.



Figure 10: Harvest in action - producing narrow chaff rows for burning the following autumn. (Photo: A Storrie)

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M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www. grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control

M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www. grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control





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 <u>destruction</u>—nutrient Losses: comparing chaff heaps with narrow windrows

Weed seed bank destruction-vary windrow placement to avoid potassium concentration



GRDC/Grassroots Agronomy: Narrow windrow burning in southern NSW

GRDC Report: Developments in stubble retention

IWM Section 4. Tactics



Figure 11: Windrow burning. (Photo: Penny Heuston)

12.6.3 Chaff carts



Figure 12: Chaff cart in action at Tarin Rock, Western Australia. (Photo: A Storrie)

au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

Chaff carts are towed behind headers during harvest to collect the chaff fraction as it exits the harvester (Figure 6). Collected piles of chaff are then either burnt the following autumn or used as a source of stock feed. 19

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%

GRDC. Section 6: Managing weeds at harvest. GRDC Integrated Weed Management Hub, http://grdc.com.



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Weed seed bank destruction-an integrated approach to weed management

Weed seed bank destruction-more efficient use of chaff

Weed seed bank destruction—wild radish

Weed seed bank destruction—burning chaff dumps

Weed seed bank destruction-seeing results from integrated weed management



information

IWM Section 4. Tactics



More information

AHRI: Weed Destructor integrated into harvester

IWM Section 4: Tactics

Collected chaff must be managed to remove weed seeds from the cropping system. 20

12.6.4 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. 21

of wild radish seeds entering the front of the header during the harvest operation.

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. ²²

As well as being an effective system for weed-seed removal, the baled material can have a substantial economic value as a feed source. However, as with all baling systems, consideration must be given to nutrient removal. 23

For the story of development of header-towed baling systems, see: http://www.glenvar. com/.

12.6.5 Harrington Seed Destructor

The Harrington Seed Destructor (HSD) is the invention of Ray Harrington, a progressive farmer from Darkan, Western Australia. Developed as a trail-behind unit, the HSD system comprises a chaff-processing cage mill, 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. 24

12.6.6 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.

Evaluation under commercial harvest conditions by AHRI has determined that the HSD process will destroy ≥95% of annual weed seed during harvest. A new version of the HSD, a prototype 'Integrated Weed Destructor', has been developed by engineers at the University of SA in collaboration with AHRI. It is mounted within the rear of the harvester. Testing and development are under way. 25,26



GRDC Videos

IWM—Harrington Seed Destructor (3 videos)

Weed seed destruction—beer can height

Weed seed bank destruction-lessons <u>learned</u>—windrowing canola

Weed seed bank destruction-Spear grass (Bromus spp.) an emerging problem

- M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www. grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control
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- M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www. grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control
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- M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www. grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control
- AHRI (2013) Weed Destructor integrated into harvester. AHRI, University of Western Australia, http://ahri. uwa.edu.au/weed-destructor-integrated-into-harvester/

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Grassroots Agronomy: Narrow windrow burning in southern NSW

GRDC Fact Sheets: Managing the weed seedbank

GRDC Ground Cover: Harvest systems combined to crush weed-seed resistance

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

12.7 Summary

Productive, large-scale conservation cropping as practised across large areas of the Australian grainbelt is reliant on herbicides for the management of weed populations. This reliance has produced, and continues to produce, widespread occurrence of herbicide-resistant weed populations. Herbicide dependency and resulting loss of effective herbicides is constraining effective grain crop production. Consequently, producers are farming to control weeds instead of for grain crop production. Harvest weed-seed control provides the opportunity to manage weed populations more effectively and to move away from reliance on herbicidal weed control. The consequence is that growers regain flexibility in the overall management of their cropping program. 27



GRDC Update

Development of the Harrington Seed **Destructor**

The nuts and bolts of efficient and effective windrow burning

Windrow burning for weed control—WA fad or viable option for the <u>east</u>



GRDC Videos

GCTV1: Integrated weed control & HSD

GCTV10: Harvester mounted weed destructor

GRDC Webinar: A beginner's guide to harvest weed seed control

IWM-Weed seed capture at harvest (5 videos)

GCTV15: Harvest weed seed control

Weed seed destruction—weed seed management

Weed seed destruction-weed seed capture

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



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 <u>dumps</u>

WeedSmart: Narrow windrow burn like a pro

WeedSmart: Setting up your header for harvest weed seed control

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M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www. grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control



SECTION 13

Storage

An on-farm storage system designed for good hygiene that includes aeration and sealable silos for fumigation is essential for growers who wish to maximise their returns from barley (Figure 1). Without sealable silos, growers could be contributing to Australia's problem of insect resistance to phosphine, the most common fumigant used in the Australian grain industry. Without aeration, growers risk excluding themselves from markets that will not accept chemically treated grain.

In conjunction with sound management practices, which include checking grain temperatures and regular monitoring for insect infestations, an on-farm storage system that is well designed and maintained and properly operated provides the best insurance a grower can have on the quality of grain to be out-turned.



Figure 1: Storage with aeration is important for protecting Australia's markets. (Photo: DAF Qld)
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. ¹ Effective management of stored grain can eliminate all of these risks to grain quality.

Target grain temperatures of stored wheat should be 20–23°C during summer and <15°C in winter. ² Aerated silos, properly managed, should allow growers to target an average summertime grain-storage temperature of 20°C.

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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

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13.1 How to store barley on-farm

13.1.1 Malt barley

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 use of agricultural chemicals or application of dry heat.

GRDC-funded CSIRO research shows that by understanding and carefully manipulating the storage process, post-harvest dormancy can be removed without compromising barley quality.³

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. ⁴

13.1.2 Storage options

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 ways to store wheat 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.

Table 1: Advantages and disadvantages of grain storage options

		•
Storage type	Advantages	Disadvantages
Gas-tight sealable silo	 Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects Easily aerated with fans Fabricated on-site or off-site and transported Capacity from 15 to 3000 t Service life up to 25 years or more Simple in-loading and outloading Easily administered hygiene (cone base particularly) Can be used multiple times inseason 	 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





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CSIRO and Barrett Burston Malting Co. The effect of storage conditions on post-harvest maturation and maltability of barley. E-Malt, https://www.e-malt.com/statistics/ScientificDigest/BTSbarleyStorage.pdf

⁴ CSIRO (2011) Stored barley manipulated to brew better beer. CSIRO Food and Agriculture June 2010, Updated October 2011.





Storage type	Advantages	Disadvantages
Non-sealed silo	 Easily aerated with fans 7-10% cheaper than sealed silos Capacity from 15 to 3000 t Service life up to 25 years or more Can be used multiple times inseason 	 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 Western Australia 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 Are 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 Need to dispose of bag after use Single-use only
Grain storage sheds	 Can be used for dual purposes Service life 30 years 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 is 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 able to 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. 5

The Kondinin Group National Agricultural Survey 2009 revealed that 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 that only 36% of growers using phosphine applied it correctly—in a gas-tight, sealable silo.

Research shows that 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 2). Fumigation trials



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C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right - do it once: A Grains Industry Guide. (Reprinted 2013) GRDC, http://www.grdc.com.au/uploads/documents/ GRDC-Fumigating-with-Phosphine-other-fumigants-and-controlled-atmospheres.pdf?shortcut=1



in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks (Figure 3). The rest of the silo also suffers from reduced gas levels. ⁶

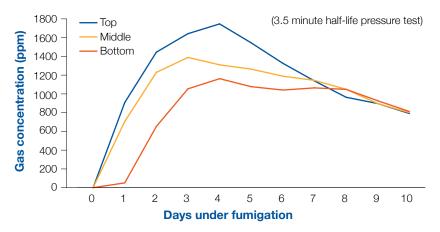


Figure 2: Gas concentration in gas-tight silo. (Source: DAF Qld)

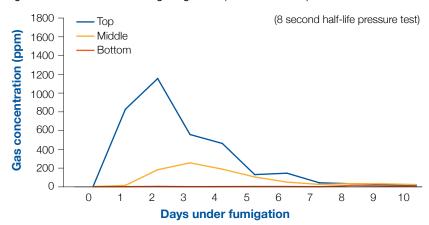


Figure 3: Gas concentration in a non-gas-tight silo. (Source: DAF Qld)

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.

Aeration controllers that automatically monitor air temperature and humidity are designed to turn fans on and off at the optimum times. The controller reduces the risk of having fans running on storages at times that may cause grain damage. Most aeration controllers have hour meters fitted, so run-times can be checked to ensure that they are within range of the expected total average hours per month (e.g. 100 h/month).

Aeration systems commonly used for 'aeration cooling' should be separated from those designed specifically to achieve reliable 'aeration drying'. Serious grain damage has occurred when fan performance has not met the required airflow rates as measured in litres per second per tonne (L/s.t). If aeration drying of grain is attempted with elevated moisture levels and using an inadequate airflow rate and/or a poor system design, sections of the storage can develop very high moisture and grain temperatures. With low airflow rates, moisture-drying fronts move too slowly to prevent grain spoilage. Grain-quality losses from moulds and heat occur rapidly. This type of damage often makes the grain difficult to sell and may cause physical damage to the silo. ⁷

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P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. Grain Storage Fact Sheet, GRDC, September 2010, http://www.grdc.com.au/~/media/FC440FBD7AE14140A08DAA3F2962E501.pdf

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More

GRDC: Fumigating with phosphine,

other fumigants and

controlled atmospheres

information



February 2016

Researchers in Australia have developed a device that measures working airflow rates of fans fitted to grain storage. Called the 'A-Flow', it has been validated under controlled conditions, using an Australian Standard fan-performance test rig, to be within 2.6% of the true fan output. The device was used on a typical grain storage that was in the process of aerating recently harvested grain. A fan advertised to provide 1000 L/s (equivalent to 6.7 L/s.t on a full 150-t silo) was tested and shown to be producing only 1.8 L/s.t. Because of this test, the farmer recognised a need to make changes to his current aeration system design.

A number of changes may be required if airflow rates are not suitable for efficient aeration cooling or drying. A new fan that is better suited to the task could be installed, or the amount of grain in the silo reduced to increase flow rate per tonne of grain.

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'.

13.2 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 (Figure 4). Try to bury grain or spread unwanted grain out to a shallow depth of <20 mm so that insects are exposed to the daily temperature extremes and other insect predators.



Figure 4: Poor grain hygiene undermines effective stored grain insect control. (Photo: DAF Qld) A trial in Queensland revealed >1000 lesser grain borers (Rhyzopertha dominica) (Figure 5) in the first 40 L of grain through a harvester at the start of harvest; this harvester

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was considered reasonably clean at the end of the previous season. ⁸ Further studies in Queensland revealed that insects are least mobile during the colder winter months. Cleaning around silos in winter can reduce insect numbers before they become mobile.



Figure 5: Rhyzopertha dominica. (Photo: DAF Qld)

Successful grain hygiene involves cleaning all areas where grain residues become trapped in storages and equipment. Grain pests can survive in a tiny amount of 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.

13.3 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 PRF grain does not rule out the use of some fumigants, including phosphine (Figure 6). However, PRF grain should not have any chemical residues from treatments that are applied directly to the grain as grain protectants.



GRDC Fact Sheets:
Hygiene and structural
treatment for grain
storages





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P Burrill, P Botta, C Newman, B White, C Warrick (2013) Grain storage pest control guide. Northern and southern regions. Grain Storage Fact Sheet, GRDC, 25 June 2013, https://www.grdc.com.au/Resources/Factsheets/2013/06/Grain-Storage-Fact-Sheet-Grain-Storage-Pest-Control-Guide



Before using a grain protectant or fumigant, growers need to check with prospective buyers, because the use of some chemicals may exclude grain from certain markets.

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 pockets where the fumigant may fail to penetrate, and by retreating it with an alternative disinfestant or protectant. ⁹



Figure 6: Phosphine is widely accepted as having no residue issues. (Photo: DAF Qld)
Research has identified the genes responsible for insect resistance to phosphine.
A genetic analysis of insect samples collected from south-eastern Queensland between 2006 and 2011 has allowed researchers to confirm the increasing incidence of phosphine resistance in the region. Whereas few resistance markers were found in insects collected in 2006, by 2011, most collections had insects that carried the resistance gene. Further testing with DNA markers that can detect phosphine resistance is expected to identify problem insects before resistance becomes entrenched, thereby helping to prolong phosphine's effective life, as well as increasing the usefulness of the break strategy. 10

According to research at Department of Agriculture and Fisheries Queensland, 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 licenced fumigator.

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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/Phosphine Strategy.pdf

D Schlipalius (2013) Genetic clue to thwart phosphine resistance. GRDC Ground Cover, Issue 102, Jan.– Feb. 2013, http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-102/Genetic-clue-to-thwart-phosphine-resistance



Table 2: Resistance and efficacy guide for stored grain insects (northern and southern regions) in cereal grains

WHP, Withholding period (days). Note: Pirimiphos-methyl, combined products such as Reldan Plus PGR and chlorpyrifos-methyl are not registered for use on malt barley. For more information, see p. 121, Table 2, of the NSW DPI Winter crop variety sowing guide 2015, or visit APVMA

	110	W Bi i William	orop varioty oo	wing galac z	013, OF VISIT AF VIVIA			
Treatment and example product	WHP	Lesser grain borer	Rust-red flour beetle	Rice weevil	Saw- toothed grain beetle	Flat grain beetle	Psocids (booklice)	Structural treatments
Grain disinfestants—used	d on infes	ted grain to	control full lif	e cycle (adı	ults, eggs, larvae,	pupae)		
Phosphine (Fumitoxin®) AB when used in gastight, sealable stores	2							
Sulfuryl fluoride (ProFume®) ^C	1							
Dichlorvos (e.g. Dichlorvos 1140®) ^D	7–28							к
Grain protectants—applie	ed postha	arvest. Poor	adult control	if applied to	o infested grain			
Pirimiphos-methyl (Actellic 900®)	nil ^H							
Fenitrothion (Fenitrothion 1000®) ^E	1–90					_		
Chlorpyrifos-methyl (Reldan Grain Protector®) ^F	Nil ^H							
Methoprene (Grain Star 50®)	Nil		J		J			
Combined product' (Reldan Plus IGR Grain Protector)	Nil ^H							
Deltamethrin (K-Obiol®)C	Nil^H							
Diatomaceous earth, amorphous silica—effective internal structural treatment for storages and equipment. Specific-use grain treatments								
Diatomaceous earth, amorphous silica (Dryacide®) ^G	Nil ^H							
		Not registered	d for this pest					

High-level resistance in flat grain beetle has been identified, send insects for testing if fumigation failures

Resistant species likely to survive this structural treatment for storage and equipment Resistance widespread (unlikely to be effective)

Effective control

^A Unlikely to be effective in unsealed sites, causing resistance, see label for definitions.

^BTotal of (exposure + ventilation + withholding) = 10–27 days.

^cRestricted to licenced fumigators or approved users.

^D Restriced to use under permit 14075 only; unlikely to be practical for use on farm.

E Nufarm label only.

F Stored grains except malting barley and rice/ stored lupins registration for Victoria only/ not on stored maize destined for export.

^G Do not use on stored maize destined for export, or on grain delivered to bulk-handling authorities.

^HWhen used as directed on label.

¹When applied as directed, do not move treated grain for 24 hours.

^JPeriods of 6–9 months storage including mixture in adulticide, e.g. fenitrothion at label rate.

^K Dichlorvos 500 g/L registration only.

Source: Registration information courtesy of Pest Genie, APVMA and InfoPest (DEEDI).

Field trials have shown that SF can control strong phosphine-resistant populations of rusty grain beetle (Cryptolestes ferrugineus). Monthly sampling of fumigated grain has revealed no live insects for three consecutive months in large-scale bunker (pad) storages after the fumigation.

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.



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Complimentary laboratory experiments have shown that phosphine resistance does not show cross-resistance to SF, which is an additional advantage of using SF. 11

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.

To find out more, visit the GRDC Grains Industry Guide: Fumigating with phosphine, other fumigants and controlled atmospheres. Do it right - do it once.

Two other grain protectants are now available:

- 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. Insectresistance surveys in the past consistently detected low levels of deltamethrinresistant insect strains in the industry. This is a warning that 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. 12
- Conserve On-Farm. Has three 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.

A grain disinfestant combined with carbon dioxide gas currently has some limitations:

 VAPORMATE (active ingredient ethyl formate 166.7 g/kg). 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 licenced fumigator.

Controlled atmosphere/non-chemical treatment options include:

- Carbon dioxide (CO2). Involves displacing the oxygen inside a gas-tight silo with a high concentration of CO2 combined with a low oxygen atmosphere lethal to grain pests. To achieve a complete kill of all grain pests at all life-stages, CO2 must be maintained at a minimum concentration of 35% for 15 days.
- Nitrogen (N₂). Provides insect control and quality preservation without chemicals. It is safe to use and environmentally acceptable, and the main operating cost is electricity used by the equipment to produce N₂ gas. The process uses pressure swing adsorption (PSA) technology to produce N₂, thereby modifying the atmosphere within the grain storage to create a very high concentration of N₂, and starving insect pests of oxygen. 13 There are no residues, so grains can be traded at any time.

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M Nayak (2012) Sulfuryl fluoride—A solution to phosphine resistance? GRDC Research Update Northern Region, Spring 2012, Issue 66, https://www.grdc.com.au/~/media/ DAF5F438D9644D90B9A4FA9716B2014E.pdf

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

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 (reprinted June 2013), http:// www.grdc.com.au/uploads/documents/GRDC-Fumigating-with-Phosphine-other-fumigants-and-controlledatmospheres.pdf?shortcut=1



Silo bags as well as silos can be fumigated (Figure 7). Research conducted by Andrew Ridley and Philip Burrill from DAF Qld and Queensland farmer Chris Cook found that 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 230 t of grain successfully controlled all life stages of the lesser grain borer.



Figure 7: Silo bags can also be furnigated. (Photo: 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 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 8). In previous trials when spears were spaced 12 m apart, the phosphine gas took too long to diffuse throughout the whole bag. ¹⁴

Know more. Grow more.

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P Burrill, A Ridley (2012) Silo bag fumigation. GRDC Research Update Northern Region, Spring 2012, Issue 66, http://www.grdc.com.au/Media-Centre/Ground-Cover-Issue-96-January-February-2012/Researchers-devise-practical-silo-bag-fumigation-method



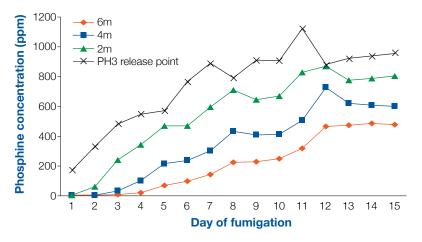


Figure 8: Spread of phosphine gas in a silo bag from a release point to gas-monitoring lines at 2, 4 and 6 m along a silo bag.

13.4 Aeration during storage

Aeration has a vital role in maintaining grain quality attributes and reducing insect pest problems in storage. Most grain in storage is best held under aeration-cooling management with the silo having appropriate roof venting. Generally, silos should be sealed up only during a fumigation operation, which typically lasts for 1–2 weeks.

Aeration typically reduces stored grain temperatures by more than 10°C during summer (Figure 9), which significantly reduces the threat of a serious insect infestation. ¹⁵

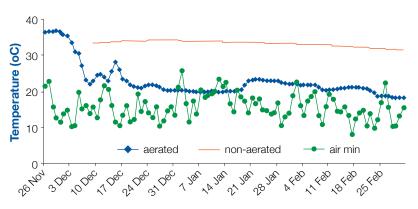


Figure 9: Comparison of wheat grain temperatures in aerated and non-aerated silos.

As soon as grain is harvested and put in storage, run the aeration system continuously for the first 5 days to reduce grain temperatures and produce uniform moisture conditions in the grain bulk. Without aeration, grain holds its heat because it is an effective insulator and will maintain its warm harvest temperature for a long time. Wheat at typical harvest temperatures of 28–35°C and moisture content >13–14% provides ideal conditions for mould and insect growth (Table 3). ¹⁶

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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

EP Burrill, P Botta, C Newman, B White, C Warrick (2013) Dealing with high-moisture grain. Grain Storage Fact Sheet, GRDC, June 2013, https://www.grdc.com.au/~/media/Documents/Resources/Publications/Fact-sheets/GSFS-7 HighMoistureGrain 2013 LR Final-pdf.pdf



Table 3: The effect of grain temperature on insects and mould (Source: Kondinin Group)

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

Although adult insects can survive at low temperatures, most storage-pest life-cycle stages are very slow or stop at temperatures <18–20°C. One of the more cold-tolerant pests, the common rice weevil, does not increase its population at grain temperatures <15°C. Insect-pest life cycles (eggs, larvae, pupae and adults) are lengthened from the typical 4 weeks at warm temperatures (30–35°C) to 12–17 weeks at cooler temperatures (20–23°C).

Research also shows that cereals at 12% moisture content stored for 6 months at $30-35^{\circ}\text{C}$ (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%. ¹⁷ Special measures must be taken to minimise the risk of insect infestations or heat damage if the crop is harvested in damp conditions.

A trial by DAF Qld revealed that high-moisture grain generates heat when put into a confined storage, such as a silo. Wheat with 16.5% moisture content at a temperature of 28°C was put into a silo with no aeration. Within hours, the grain temperature reached 39°C and within 2 days reached 46°C, providing ideal conditions for mould growth and grain damage (Figure 10). ¹⁸

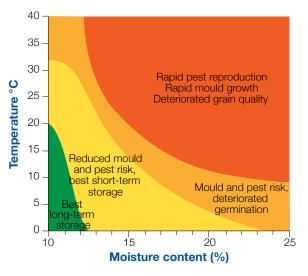


Figure 10: Effects of temperature and moisture on stored grain. (Source: CSIRO Ecosystems sciences as published in Grain Storage Fact Sheet—dealing with high-moisture grain)

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

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Wheat Quality Objectives Group (2009) Understanding Australian wheat quality. GRDC, http://www.grdc.com.au/~/media/6F94BAEDA4E04E66B02AC992C70EB776.pdf

P Burrill, P Botta, C Newman, B White, C Warrick (2013) Dealing with high-moisture grain. GRDC Grain Storage Fact Sheet, June 2013, https://www.grdc.com.au/~/media/Documents/Resources/Publications/Fact-sheets/GSFS-7 HighMoistureGrain 2013 LR Final-pdf.pdf



managed by aerating until drying equipment is available. Blending with low-moisture grain and aerating is also a commonly used strategy (Figure 11).

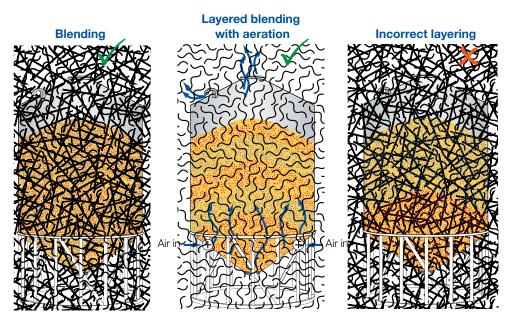


Figure 11: Correct blending. (Source: Kondinin Group)

Aeration drying forces large volumes of air through the grain in storage and slowly removes moisture. Supplementary heating can be added when ambient conditions typically have high humidity. Aeration drying can be done in a purpose-built drying silo or a partly filled silo with high-capacity aeration fans.

Dedicated driers can be used to dry grain in batches or with continuous-flow, before it is put into silos, but excessive heat applied postharvest can reduce quality.

13.5 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 2 weeks is advisable. Insect pests present in the on-farm storage must be identified so that 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 (Figure 12). ¹⁹



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P Burrill, P Botta, C Newman (2010) Aeration cooling for pest control. Grain Storage Fact Sheet, GRDC, September 2010, https://www.grdc.com.au/~/media/ReFocus-media-library/Document/GRDC-Document-Store/Publications-Media-and-Communications/Factsheets/Grain-storage-FS-Aeration-cooling-for-pest-control.pdf





Figure 12: Keep records of findings from stored grain insect monitoring. (Photo: DAF Qld)

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.), the 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 these pests can be found in the GRDC Grain Storage Fact Sheet Northern and southern regions stored grain pests—Identification, or the GRDC Stored grain pests identification. The Back Pocket Guide.

The Fact Sheet outlines how to monitor stored grain for infestations. Here are some basic points to follow when monitoring for insect pests in your grain:

- Sample and sieve grain from the top and bottom of grain storages every 4 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. 20

NOTE: Exotic pests including Karnal bunt (*Tilletia indica*) and khapra beetle (*Trogoderma granarium*) are a threat to the Australian grains industry—report sightings immediately.

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P Burrill, P Botta, C Newman, B White, C Warrick (2013) Stored grain pests—identification. Northern and southern regions. Grain Storage Fact Sheet, GRDC, June 2013, https://www.grdc.com.au/~/media/Documents/Resources/Publications/Fact-sheets/GSFS-2_SGPestIdent_NS_2013_LR_Final-pdf.pdf



SECTION 14

Environmental issues

FAQ 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. These losses are direct losses from crops damaged by frost and indirect from growers missing opportunities. Because of the variability in the incidence and severity of frost, a number of management strategies should be utilised in a farm management plan.

Key points:

- 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 5-7 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. 1

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. 2

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 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.



Know more. Grow more.

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GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc. com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc. com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;



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 how far below 0°C it falls. 3

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.

Measuring temperature at Stevenson screen height (1.2 m) will not be the same as at the canopy height, and the more remote the measurement is from the actual crop site, the less accurate it will be. Temperature measured above bare ground may not be a reliable indicator of the temperature of air surrounding susceptible plant parts, and certainly not a good indicator of the temperature of the plant parts themselves.

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.

A rule-of-thumb is that 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. 4

14.1.3 The changing nature of frost in Australia

The length of the frost season has 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 that 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 eastern Australian grainbelt, the window of frost occurrence has broadened, so frosts are occurring both earlier and much later in the season (Figure 1). In the Western Australian grainbelt, there are fewer earlier frosts and a shift to frosts later into the season.

The frost window has lengthened by 3 weeks in the Victorian grainbelt and by 2 weeks in the New South Wales grainbelt. The frost window in Western Australia and Queensland has statistically remained the same. The eastern South Australian sites are similar to Victoria, and sites in the west of South Australia are more like Western Australia. Northern Victoria seems to be the epicentre of the change in frost occurrence (Figure 2), with some locations experiencing a broadening of the frost season by 53 days.



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GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc. com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc. com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

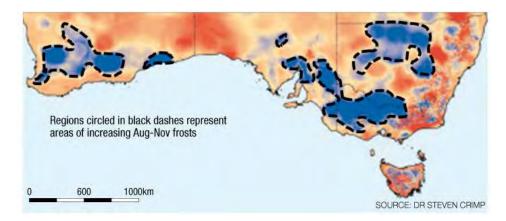


Figure 1: Regions of increasing August-November frosts.(Source: Steven Crimp, CSIRO)

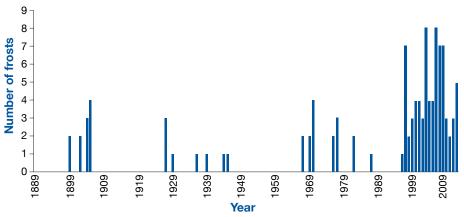


Figure 2: Historical number of frosts in the flowering window 20 September–30 October for Yitpi $^{\circ}$, Longerenong, Victoria.

14.1.4 How does frost affect crops?

The ways in which frost can affect crops are complex. It has several effects on plants including cold, desiccation and freezing.

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 or chilling, desiccation, and finally freezing (Figure 3). It is a step-wise response (i.e. desiccation will not occur without prior cold damage, 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 the ice nucleation and formation.

1. Cold or chilling damage occurs when plants are exposed to temperatures <10°C, down to -2°C (Figure 3). 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.</p>



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- 2. 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.
- 3. 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, etc.

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 4.). Losses in grain yield and quality from frost primarily occur between stem elongation and late grain-filling.

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 5–7 days after the frost event has occurred. ⁵

14.1.5 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 that 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. ⁶

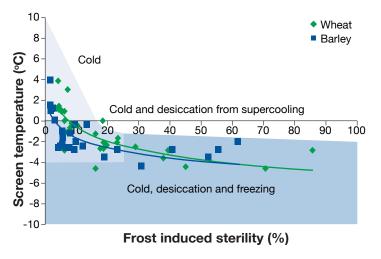


Figure 3: Average frost-induced sterility in flowering heads of wheat and barley versus minimum Stevenson screen temperature from frosts at trials from WA, SA and NSW frost nurseries 2010–14.



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Susceptibility to frost damage

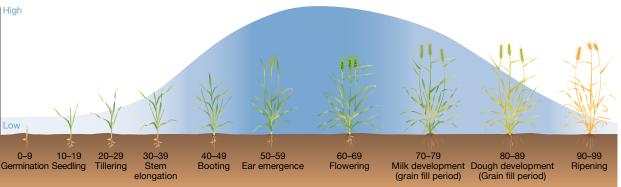


Figure 4: Susceptibility of cereals to frost during the development cycle, with Zadoks growth stages depicted.

14.1.6 Risk management for frost

The variability in the incidence and severity of frost means that 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.⁷

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. Consider your 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 your 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
 manager; 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. ⁸





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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. 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 preflowering and as late as 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 5). 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. ⁹ Agronomic practices that may assist with storing heat in the soil heat
 bank include:
 - i. Practices that alleviate non-wetting sands, such as clay delving, mould-board ploughing or spading. These practices 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 has reduced frost damage and prepares the surface for hay cutting should it be necessary.
 - iii. 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 have had a detrimental effect on yield under frost.
 - iv. 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.
 - v. Cross-sowing. Crops sown twice with half the seed sown in each direction have a more even plant density, and this has been shown to 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.





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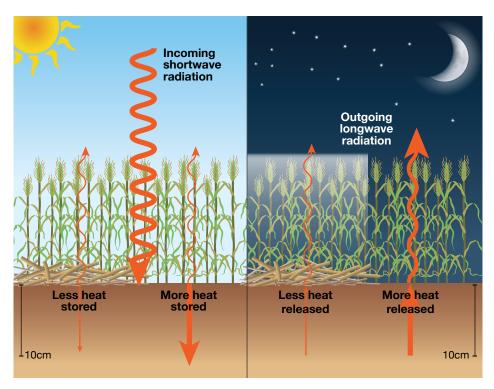


Figure 5: Soil heat bank, illustrating the role it plays in capturing heat during the day and radiating heat into the crop canopy overnight to warm flowering heads and minimise frost damage.

- Step 4. Select appropriate crops. Crop selection is an important factor to consider for frost-prone paddocks. 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. Flower Power (from Department of Agriculture and Food WA) and Yield Prophet are useful tools 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:
 - i. Use more than one variety, and varieties with different phenology drivers, and manipulate sowing date so that crops flower over a wide window throughout the season. Flowering later than the frost window will invariably result in low yields due to heat and moisture stress.
 - ii. Stage sowing dates over 3–6 weeks. If sowing just one variety, this would provide a wide flowering window. If the whole program is set to flower over a 2-week period, it is exposed to risk of greater 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 that some crop will be frosted but the aim is to reduce extensive loss.
 - iii. To minimise frost risk, a mix is needed of sowing dates, crop types and maturity types to incorporate different frost-avoidance strategies into the cropping system. In years of severe frost, regardless of the strategy adopted, it may be difficult to prevent damage.
 - iv. Trials have shown that 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.



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- v. 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. Ranking information for current wheat and barley varieties for susceptibility to reproductive frost will soon be available from the National Variety Trials website (Figure 6). This information 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: Figure 7 shows the ranking of adapted wheat varieties for the low-medium rainfall cropping areas of the Southern Region. A grower may be considering how to incorporate La Trobe(and Scope CL(into their cropping program to complement Hindmarsh. From a frost-risk-management perspective, La Trobe(has a slightly higher sterility under frosts than, and the same sowing/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 5–7 days earlier with a slightly lower frost risk than Hindmarsh.



Figure 6: Frost research is being funded by the GRDC under the National Frost Initiative, and barley variety rankings will soon be available. ((Photo: Emma Leonard)





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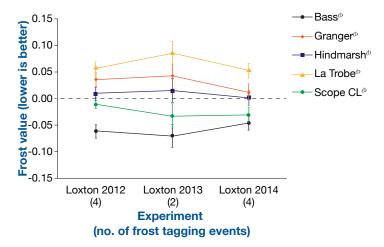


Figure 7: Frost value (FV) of sterility under flowering frost for five barley varieties tested at Loxton South Australia. FVs are presented along with prediction standard error bars. The number of frost events is indicated in parentheses for each site/year. Lower FVs are better.

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 Western Australis and in South Australia have shown that grazing of wheat 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. ¹⁰

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.

Post-frost-event 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 incurred.

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





¹⁰ GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;



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 (e.g. 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 is to return organic matter and nutrients to the soil, manage crop residues, weeds and improve soil fertility and structure. The economics need to be considered carefully. ¹¹

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 grain-filling, 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 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, there
 may be 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.

Frosted grain is in the category 'Frost Damaged', for which there is a maximum limit of 5% for Malt grades and 10% for Feed grades.

Higher classification of frost-affected grain may be achieved by cleaning grain, but the capacity and economics need to be carefully considered. ¹²





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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 1 year. 13

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 bank 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, remain conscious of 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 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. 14

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:

Genetics: developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.





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GRDC Ground Cover: Extreme weather events on the rise

GRDC Ground Cover: Issue 114—Climate forecasting

GRDC Update Papers: Agronomist's guide to information for managing weather and climate risk

GRDC Fact Sheets: Farm Business Management: Making effective business decisions

GRDC Fact Sheets: Farm business management: Simple and effective business planning

GRDC: Cereal growth stages

NVT: Zadoks growth <u>scale</u>

GRDC Video: Frost Initiative playlist

GRDC Ground Cover: Issue 109-Frost

GRDC Back Pocket Guide: Cereals-frost identification

GRDC: Managing frost risk—a guide for southern Australian grains

DAFWA: Frost and cropping

AWB: Wheat Quality **Fact Sheet**

- 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. 15

Useful tools

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

14.1.11 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 grain-filling, and when canopy temperatures fall below 1°C in your paddock.
- 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
- 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. You will need to 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 Figure 8b 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 grain filling are continuing. Normal grain should be extending at ~1 mm every 2 days until the full length is achieved. 16

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 2 days may show anther damage, and after 4 days should reveal whether grain 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.



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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 8 half-filled with grain. This would represent a yield loss of: $8/20 \times 50\% \times 2500 = 500 \text{ kg/ha}$. ¹⁷

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 of 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. ¹⁸

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 (Figures 8 and 9.)

Carefully dissect through the leaf sheaths with a sharp knife to find the approximate position of the head and then un-wind the remaining tissue to expose the small head. At this stage of development, the frosted heads/tillers will not emerge (Figure 8a) and the crop will re-tiller.

Frost damage to the stem may be evident as blistering and bleaching of the stem internodes (Figure 8a). Sometimes this is associated with damage to the head, but not always, as in Figure 10, where the stem is damaged but not the developing head.

Experience in the 2014 season indicates that crops can re-tiller and achieve reasonable yield levels, provided temperatures are favourable and either soil moisture is good or spring rainfall is adequate. ¹⁹





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¹⁷ GRDC National Frost Initiative and associated partners (2016) GRDC Tips and Tactics, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

¹⁸ GRDC National Frost Initiative (2016) and associated partners, GRDC Tips and Tactics. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;

¹⁹ GRDC National Frost Initiative (2016) and associated partners, GRDC Tips and Tactics. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative;





Figure 8: (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, 2–3 weeks later. (Photos: (a) Karl Moore and (b) Ben Biddulph, DAFWA)

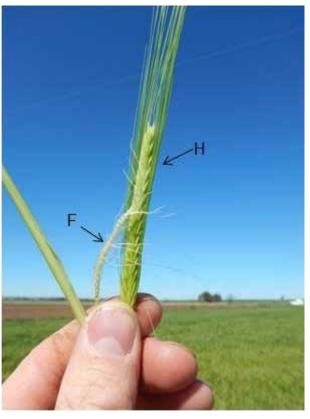


Figure 9: Damage to the developing barley head from frost at stem elongation ~GS35; frosted head (F) and healthy head (H). Photos were taken at 2–3 weeks after the frost at ~GS49. (Photo: Ben Biddulph, DAFWA)



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Figure 10: Damage to the stem internodes, but viable head. (Photo: Ben Biddulph, DAFWA)

Head damage: 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; Figure 11, left panel) to light green (GS51; Figure



A



11, 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.







Figure 11: 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, 2–3 weeks after the frost events. (Photos: Sarah Jackson)

Head damage at flowering: cold and desiccation damage during flowering

Cold and desiccation damage to wheat heads after partial or complete head emergence (GS51 onwards) can occur when canopy temperature drops to \leq 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 Figures 12 and 13. A digital microscope is useful for aiding identification. ²⁰

During normal head development, immature anthers are light green, turning yellow on maturity just prior to flowering (Figure 13a) and prior to extruding from the floret. Healthy anthers turn from yellow prior to pollen release (Figure 13a) to white after they have released the yellow pollen (Figure 13b, c)

After a frost event, the anther may remain light green to yellow for 1–2 days before turning white and shrivelled (as in Figure 13*d*). 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 (Figure 13b, 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 (Figure 13a). A fertilised stigma has a light coating of yellow pollen cells and curls up (Figure 13b, c), whereas a frost-affected, unfertilised stigma will become off-white to brown and shrivelled in appearance (Figure 13d).



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Figure 12: A head frosted at flowering (GS65) (left) compared with an unfrosted head at 2–3 days after the frost event, when at GS70.2. (Photo: Pia Scanlon, DAFWA)

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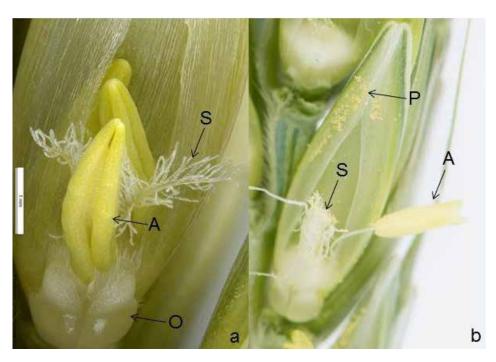
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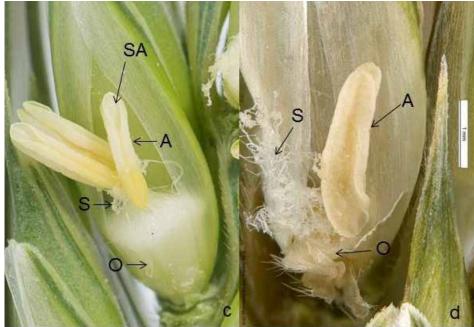


Figure 13: (a) Healthy floret about to flower: anthers (A), stigmas (S) and ovaries (O) of wheat within a floret. (b) Freshly fertilised floret: pollen (P). (c) Fertilised and swollen ovule: split anthers (SA). (d) Frosted floret. Photo of frosted floret taken at GS70.2 of heads frosted just prior to 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 (Figure 14).



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Head damage at flowering: 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 (Figure 14).

Blighting usually affects only a small proportion of the heads as in Figure 14, but is also often associated with frost damage to the reproductive structures inside, which requires closer inspection (as in Figure 13, above).

After about 1 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, and 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 grain filling. ²¹



Figure 14: 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 7 days later at GS61. (Photo: Pia Scanlon, DAFWA)

Head damage after flowering: freezing damage during grain development and grain-filling

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 Figure 15; GS70.2–79), the developing grains may be frozen and do not continue to develop. It turns a white to grey colour and becomes 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.





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When frosted during dough development and grain-filling (GF in Figure 15; 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 Figure 15 where the same head has damage from frost at flowering (GS61), grain development (GS70.8) and early grain filling (GS81). These symptoms also change over time depending on the time since the frost damage occurred (Figure 16).

Wheat that has been frosted at the grain-filling stages is a little more resilient to the effects of frost, often showing grains with shrunken sides, 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 (Figure 17).

It is not recommended to keep frost-affected grain for sowing the following year; germination may be reduced. $^{\rm 22}$

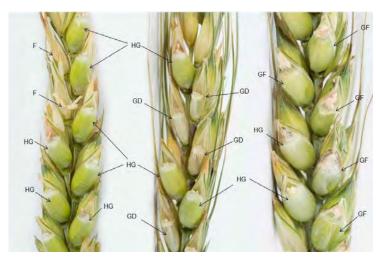


Figure 15: Wheat head that has been frosted at flowering (GS65; F) and at grain development (GS70.8; GD), and partially frosted during grain filling (GS81; GF). Frost-affected grains starting to shrivel (GD) to form a pinched or scalloped appearance (GF) compared with healthy grains (HG). Frosts occurred at ~GS65, GS70.8 and GS81, and the photo was taken at ~GS83. (Photo: Pia Scanlon, DAFWA)



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Figure 16: Head partially frosted at flowering (GS65; left); frosted at flowering and grain development (GS65 and GS70.8; centre); and at flowering, grain development and grain filling (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. (Photo: Pia Scanlon, DAFWA)



Figure 17: 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.



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Stem damage after flowering: freezing damage to the peduncle after head emergence during grain development and grain-filling

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 (Figure 18).

Initially, 1-3 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 (Figure 18, 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 3-7 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 scaring of the frosted section of the peduncle (Figure 18, 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 5–10 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 (Figure 18, lower panel; and Figure 19) 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. 23



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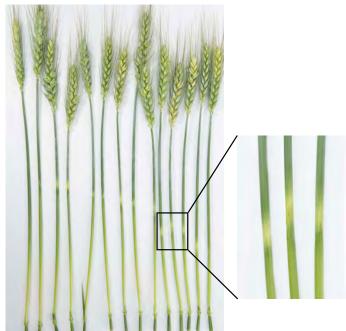


Figure 18: Upper panel: stem frost damage at the bottom/growing point of the peduncle taken the morning after a frost event. Lower panel: photo taken 3 weeks after the frost, when at GS61. The crop canopy was at ~GS55 with stem-frost-affected peduncles occurring in tillers between ear peep (GS51) and partial head emergence (GS55). (Photos: upper panel, Ben Biddulph; lower panel, Pia Scanlon, DAFWA).

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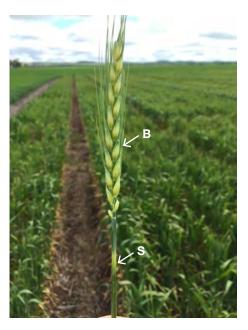




Figure 19: Peduncle stem damage showing light-green region (S) and bleached heads with infertile florets (B).

14.2 Soil moisture issues for barley

Availability of soil moisture has major interactions with the rate of transpiration and therefore photosynthetic production.

14.2.1 **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

14.2.2 Waterlogging

Barley is very susceptible to waterlogging. It 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, or on irrigation layouts with poor drainage.

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 nitrogen 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

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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

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/_ pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf



SECTION 15

Marketing

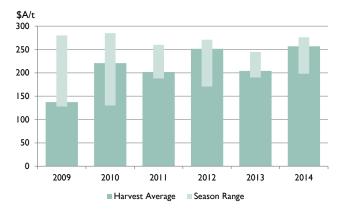
The final step in generating farm income is converting the tonnes of grain produced into dollars at the farm gate. This section provides best in-class marketing guidelines for managing price variability to protect income and cash-flow.

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 factors that are difficult to quantify, in order to establish the target price, and then working towards achieving that target price.

These factors include the amount of grain available to sell (production variability), the final cost of that production, 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 our control and difficult to predict (Figure 1).

The skills that growers have developed to manage production variability and costs can be used to manage pricing uncertainty. This section will help growers to manage and overcome price uncertainty.



Note to figure:

Pt Adelaide FI feed barley prices have varied A\$50-\$160/t over the past 6 years (25-I10% variability). For a property producing 1,000 tonne of barley this means \$50,000-\$160,000 difference in income depending on price management skill.

Figure 1: Annual price variation (season average and range) for Port Adelaide F1 feed barley.

15.1.1 Be prepared

Being prepared and having a selling plan are essential for managing uncertainty. The steps involved are forming a selling strategy, and having a plan for effective execution of sales. A selling strategy consists of when and how to sell:

When to sell

This requires an understanding of the farm's internal business factors including:

- production risk
- a target price based on cost of production and a desired profit margin
- business cash-flow requirements



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How to sell

This depends more on external market factors including:

- · time of year, which determines the pricing method
- · market access, which determines where to sell
- relative value, which determines what to sell

The key selling principles when considering sales during the growing season are described in Figure 2.

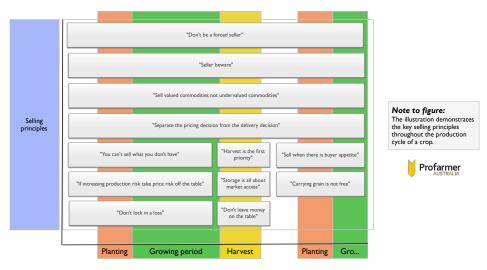


Figure 2: Grower commodity selling-principles timeline.

15.1.2 Establishing the business risk profile—when to sell

Establishing your business risk profile allows the development of target price ranges for each commodity and provides confidence to sell when the opportunity arises. Typical business circumstances of a cropping enterprise, and how the risks may be quantified during the production cycle, are described in Figure 3.

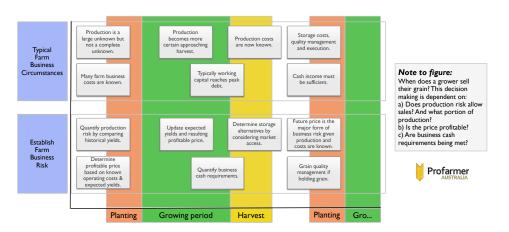


Figure 3: Typical farm business circumstances and risk.

Production risk profile of the farm

Production risk is the level of uncertainty around producing a crop and is influenced by location (climate and soil type), crop type, crop management, and time of the year.

Principle: 'You can't sell what you don't have.' Do not increase business risk by overcommitting production.



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Establish a production risk profile (Figure 4) by:

- collating historical average yields for each crop type and a below-average and above-average range
- assessing the likelihood of achieving average based on recent seasonal conditions and seasonal outlook
- revising production outlooks as the season progresses

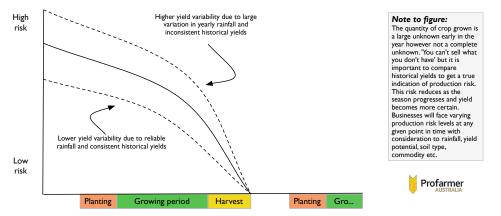


Figure 4: Typical production risk profile of a farm operation.

Farm costs in their entirety, variable and fixed costs (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.

Principle: 'Don't lock in a loss.' If committing production ahead of harvest, ensure that the price is profitable.

Steps to calculate an estimated profitable price based on total cost of production and a range of yield scenarios are provided in Figure 5.



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Estimating cost of production -	Barley	Step 1: Estimate your production potential.				
Planted Area	1,200 ha	The more uncertain your production is,				
Estimate Yield	3.2 t/ha	the more conservative the yield estimate should be. As yield falls, your cost of				
Estimated Production	3,840 t	production per tonne will rise.				
Fixed costs						
Insurance and General Expenses	\$100,000	Step 2: Attribute your fixed farm business costs. In this instance if 1,200 ha reflects				
Finance	\$80,000	1/3 of the farm enterprise, we have				
Depreciation/Capital Replacement	\$70,000	attributed 1/3 fixed costs. There are a number of methods for doing this (see M				
Drawings	\$60,000	Krause "Farming your Business") but the				
Other	\$30,000	most important thing is that in the end all costs are accounted for.				
Variable costs		costs are accounted for.				
Seed and sowing	\$42,000					
Fertiliser and application	\$144,000					
Herbicide and application	\$72,000	Step 3: Calculate all the variable costs attributed to producing that crop. This can				
Insect/fungicide and application	\$30,000	also be expressed as \$ per ha x planted				
Harvest costs	\$48,000	area.				
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				
Cartage	\$12 /t	levies and freight.				
Freight to Port	\$22 /t	Step 6: Add the "per tonne" costs to				
Total per tonne costs	\$37 /t	the fixed and variable per tonne costs calculated at step 4.				
Cost of production Port track equiv	\$216.17	•				
Target profit (ie 20%)	\$43.00	Step 7: Add a desired profit margin to arrive at the port equivalent target profitable				
Target price (port equiv)	\$256.17	price.				

Figure 5: Steps to calculate an estimated profitable price for barley.

The GRDC manual 'Farming the business—sowing for your future' also provides a cost-of-production template and tips on skills requires for grain selling, as opposed to grain marketing. ¹

Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables grain sales to be timed 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.

A typical cash flow to grow a crop is illustrated in Figure 6. Costs are incurred upfront and during the growing season, with peak working capital debt incurred at or before harvest. This will vary depending on circumstance and enterprise mix. Figure 7 demonstrates how managing sales can change the farm's cash balance.

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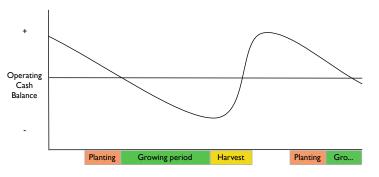
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M Krause (2014) Farming the business. Sowing for your future. GRDC, http://www.grdc.com.au/FarmingTheBusiness





Note to figure:
The chart illustrates the operating cash flow of a typical farm assuming a heavy reliance on cash sales at harvest. 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.



In this scenario peak cash surplus starts higher and peak cash debt is lower

Figure 6: Typical farm operating cash balance, assuming harvest cash sales.

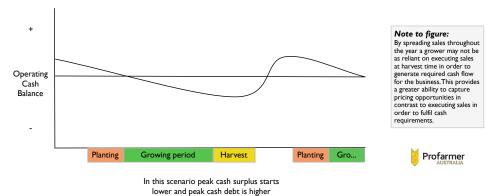


Figure 7: Typical farm operating cash balance, with cash sales spread throughout the year.

Summary

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 your price—how to sell

This is the second part of the selling strategy.

Methods of price management

The pricing methods for products provide varying levels of price-risk coverage (Table 1).

Table 1: Pricing methods and their use for various crops

	Description	Wheat	Barley	Canola	Oats	Lupins	Field peas	Chick peas
Fixed price products	Provides the most price certainty	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash	Cash	Cash	Cash
Floor price products	Limits price downside but provides exposure to future price upside	Options on futures, floor price pools	Options on futures	Options on futures	none	none	none	none
Floating price products	Subject to both price upside and downside	Pools	Pools	Pools	Pools	Pools	Pools	Pools



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Figure 8 below provides a summary of when different methods of price management are suited for the majority of farm businesses.

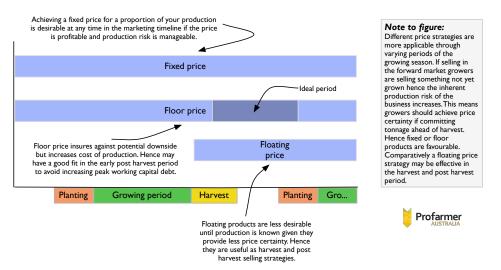


Figure 8: Price strategy timeline through the growing season.

Principle: 'If increasing production risk, take price risk off the table.' When committing 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 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 because the price is largely a known, except when there is a floating component in the price, for example, a multi-grade cash contract with floating spreads or a floating basis component on futures positions.

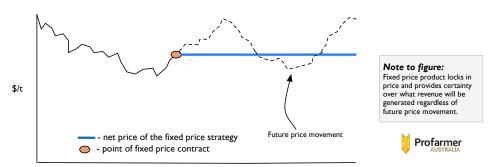


Figure 9: Fixed-price strategy.

Floor price

Floor-price strategies can be achieved by utilising 'options' on a relevant futures exchange (if one exists), or via a managed sales program product by a third party (i.e. a pool with a defined floor price strategy). This pricing method protects against potential future downside while capturing any upside (Figure 10). The disadvantage is that the price 'insurance' has a cost, which adds to the farm businesses cost of production.



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Figure 10: Floor-price strategy.

Floating price

Many of the pools or managed sales programs are a floating price where the net price received will move both 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 pre harvest.



Figure 11: Floating-price strategy.

Summary

Fixed-price strategies include physical cash sales or futures products and provide the most price certainty; however, 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; however, they cost more.

Floating-price strategies provide minimal price certainty and they are best used after harvest.

15.1.4 Ensuring access to markets

Once the selling strategy is organised, the storage and delivery of commodities must be planned to ensure timely access to markets and execution of sales. At some point, growers need to deliver the commodity to market; hence, planning on where to store the commodity is important in ensuring access to the market that is likely to yield the highest return (Figure 12).

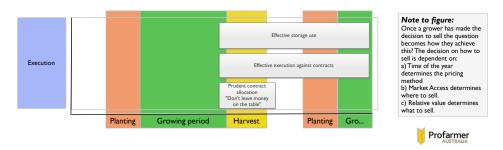


Figure 12: Effective storage decisions.



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Storage and logistics

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 around the bulk handling system, 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.' Getting the crop into the bin is most critical to business success during harvest; hence, selling should be planned to allow focus on harvest.

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-farm requires prudent quality management to ensure delivery at agreed specifications and can expose the business to high risk if this aspect is not well planned. Penalties for out-of-specification grain on arrival at a buyer's weighbridge can be expensive. The buyer has no obligation to accept delivery of an out-of-specification load. This means that the grower may have to suffer the cost of taking the load elsewhere, while also potentially finding a new buyer. Therefore, there is potential for a distressed sale, which can be costly.

On-farm storage also requires prudent delivery management to ensure that commodities are received by the buyer on time with appropriate weighbridge and sampling tickets.

Principle: 'Storage is all about market access.' Storage decisions depend on quality management and expected markets.



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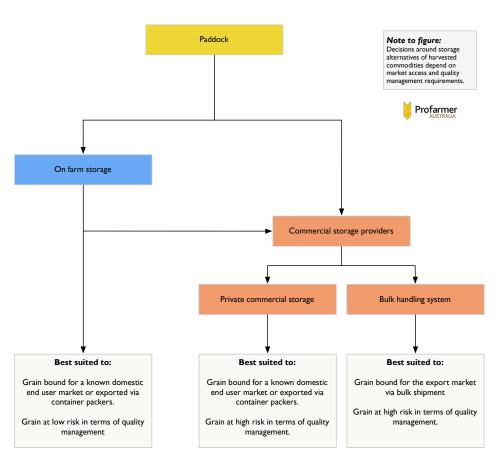


Figure 13: Grain-storage decision making.

For more information about on-farm storage alternatives and economics, refer to GrowNotes Barley Southern Region, Section 14. Grain storage.

Cost of carrying grain

Storing grain to access sales opportunities post-harvest invokes a cost to "carry" grain. Price targets for carried grain need to account for the cost of carry.

Carry costs per month are typically \$3-4/t, consisting 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 cash or against 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 what was offered at harvest. The cost of carry applies to storing grain on-farm because there is a cost of capital invested in the farm storage plus the interest component. A reasonable assumption is \$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 grain and selling it after harvest is part of the selling strategy (see Figure 14).



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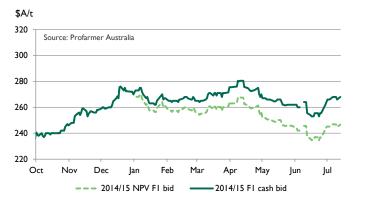
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Note to figure: If selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example in the case of a March sale of APWI wheat for March-June delivery on buyers call at \$300/t + \$3/t carry per month, if delivered in June would generate \$309/t delivered.

Figure 14: Port Adelaide F1 barley cash v. net present value (NPV).

Summary

Optimising farm-gate returns involves planning the appropriate storage strategy for each commodity to improve market access and cover carry costs in pricing decisions.

15.1.5 Executing tonnes into cash

Below are 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 includes:

- 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; and other market information pertinent to the particular commodity.
- 7. Professional services. Grain-selling professional service offerings 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 relationships. Return on investment for the farm business through improved farm-gate prices is obtained by accessing timely information, greater market knowledge, and greater market access from the professional service.
- Futures account and bank swap facility. These accounts provide access to global futures markets. Hedging futures markets is not for everyone; however, strategies that utilise exchanges such as CBOT (Chicago Board of Trade) can add significant value.

For current financial members of Grain Trade Australia, including buyers, independent information providers, brokers, agents, and banks providing over-the-counter grain derivative products (swaps), go to http://www.graintrade.org.au/membership.

For a list of commodity futures brokers, go to http://www.asx.com.au/prices/find-a- futures-broker.htm.

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; therefore, devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.



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- Quantity and quality. When entering a cash contract, you are committing to delivery of the nominated amount of grain at the quality specified. This means that production and quality risk must be managed.
- **Delivery terms.** Timing of 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
 of grain to be transferred ahead of payment; hence, counterparty risk must be
 managed.

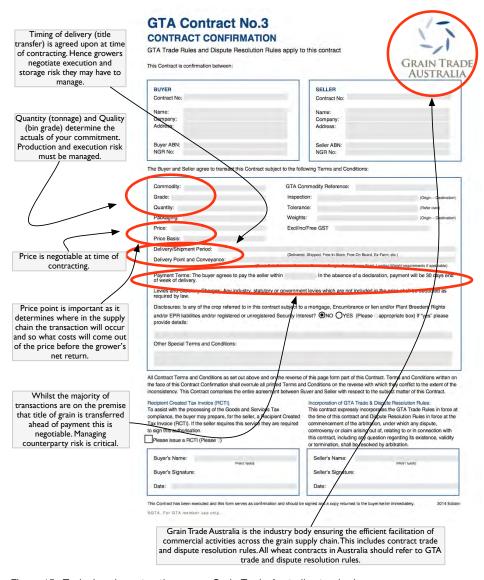


Figure 15: Typical cash contracting as per Grain Trade Australia standards.

The price point within a cash contract will depend on where along the supply chain the transfer of grain title will occur. Figure 16 depicts the terminology used to describe pricing points along the grain supply chain and the associated costs to come out of each price before growers receive their net farm-gate return.



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On ship at custo	omer wharf .								
Note to The position of the po			e to figure: price point within a cash contract will depend on re the transfer of grain title will occur along the oly chain. The below image depicts the terminology I to describe pricing points along the supply chain the associated costs to come out of each price re the growers receive their net farm gate return.						
on board omp :									
								FOB costs	FOB costs
In port terminal On truck/train a								Out-turn fee	Out-turn fee
	•								
On truck/train e					Out-turn fee	Freight to Port	Freight to Port (GTA LD)	Freight to Port (GTA LD)	Freight to Port (GTA LD)
In local silo				Receival fee	Receival fee	(GTA LD)	Receival fee	Receival fee	Receival fee
At weighbridge									
			Cartage	Cartage	Cartage	Cartage	Cartage	Cartage	Cartage
Farm gate		Levies & EPRs	Levies & EPRs	Levies & EPRs	Levies & EPRs	Levies & EPRs	Levies & EPRs	Levies & EPRs	Levies & EPRs
	Farm gate returns	Farm gate returns	Farm gate returns	Farm gate returns	Farm gate returns	Farm gate returns	Farm gate returns	Farm gate returns	Farm gate returns
	Net farm gate return	Ex-farm price	Up country delivered silo price. Delivered domestic to end user price. Delivered container packer price.	Free in store. Price at commercial storage.	Free on truck price	Post truck price	Port FIS price	Free on board price.	Carry and freight price.

Figure 16: Costs and pricing points throughout the supply chain.



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GTA: Guide to taking out contracts

GTA: Trade rules, contracts and vendor declarations

GTA: Trading standards

GrainCorp: GrainTransact Resource Centre

GrainFlow Network

Emerald Grain: Customer and grower logins

Clear Grain Exchange: Terms and conditions

Clear Grain Exchange: **Getting started**



GTA: Grain contracts managing counterparty <u>risk</u>

Clear Grain Exchange title transfer model

GrainGrowers: Counter party risk guide

Counterparty risk management: A producer perspective -Leo Delahunty

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.
- 2. 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 transferring the grain online to the buyer. The availability of this 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 firm offer and firm bid match, the parcel transacts via a secure settlement facility where title of grain does not transfer from the grower until funds are received from the buyer. The availability of this 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 title of 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.' Selling for an extra \$5/t is not a good deal if you do not receive payment.

Counterparty risk management includes the following:

- Deal only with known and trusted counterparties.
- Conduct a credit check (banks will do this) before dealing with a buyer you are unsure of.
- Sell only a small amount of grain to unknown counterparties.
- Consider credit insurance or letter of credit from the buyer.
- Never deliver a second load of grain if payment has not been received for the first.
- Do not part with title of grain before payment, or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting; alternatively, the Clear Grain Exchange provides secure settlement whereby the grower maintains title of grain until payment is received from the buyer, and then title and payment are settled simultaneously.

Above all, act commercially to ensure that the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving \$5/t more and not receiving payment 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 hold commodities that are not well priced at any given time; that is, give preference to the commodities of the highest relative value. This achieves price protection for the overall farm business revenue and enables more flexibility to a grower's selling program while achieving the business goals of reducing overall risk.

Principle: 'Sell valued commodities; not undervalued commodities.' If one commodity is priced strongly relative to another, focus sales there. Do not sell the cheaper commodity for a discount.

An example based on a wheat and barley production system is provided in Figure 17.

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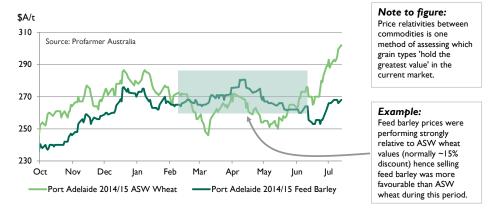


Figure 17: Port Adelaide Australian Standard White (ASW) wheat v. feed barley (AU\$/t).

Contract allocation

Contract allocation means choosing which contracts to allocate your grain against at delivery time. Different contracts will have different characteristics (price, premiums—discounts, etc.), and optimising your allocation reflects immediately on your bottom line (Figure 18).

Principle: 'Don't leave money on the table.' Contract allocation decisions do not take long, and can be worth thousands of dollars to your bottom line.

To achieve the best average barley price, growers should allocate:

- · lower grades of barley to contracts with the lowest discounts; and
- higher grades of barley to contracts with the highest premiums.

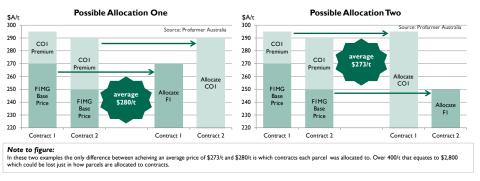


Figure 18: Examples of contract allocation of grain.

Read market signals

The appetite of buyers to purchase 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 should stand aside from the market when buyers are not as interested in buying the commodity.

Principle: 'Sell when there is buyer appetite.' When buyers are chasing grain, growers have more market power to demand a price when selling.

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 buyer appetite is strong. However, if there is one
 buyer at \$5/t above the next best bid, it may mean that cash prices are susceptible
 to falling \$5/t if that buyer satisfies their buying 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.



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Sales execution revised

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 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 Southern barley—market dynamics and execution

15.2.1 Price determinants for southern barley

Australia is a relatively small player in terms of world barley production, with \sim 5–6% of global barley production. However, in terms of world trade, Australia is a major player, exporting \sim 50–70% of the national barley crop, which accounts for \sim 20% of global barley trade.

Production and consumption of barley globally has declined over the last 30 years as the market shifts towards alternative commodities (Figure 19). The demand that remains, however, represents consumers who are more reluctant to shift to other commodities; hence, global demand tends to be relatively inelastic.

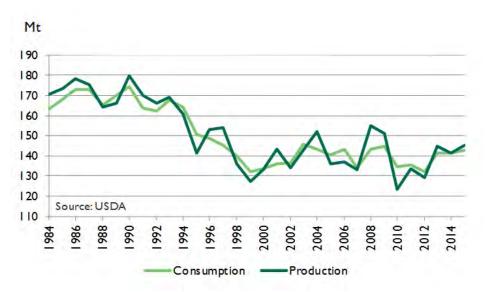


Figure 19: Global barley production v. consumption.

This is particularly true for malting barley, which cannot be substituted. Hence, whilst demand is small compared with other grains, it tends to be inflexible. 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.

In South Australia, ~80% of annual production is exported; however, in Victoria the domestic market (comprising both malt and feed demand) consumes >60% of the average Victorian barley crop. As a result, barley prices in Victoria and southern New South Wales can trade at large premiums to global values in the event of below-average production given there can be little exportable surplus.





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When Southern Australia has a large crop, local barley values should largely correlate to global prices. Hence, the timing of harvest in major exporting and importing countries is a considerable influence of prices (Figure 20), along with the consideration of malt *v.* feed demand.

The Middle East, particularly Saudi Arabia, is a very important market for South Australian feed barley, along with Japan and, more recently, China. Demand from China tends to be heavily influenced by local feed-grain policies and, hence, can be highly variable from one season to another.

International trade prices are often the best indicators of where South Australian barley values will trade. Barley values are also influenced by price relativities to wheat in the local feed grain markets. Feed barley and wheat are largely substitutable in the ruminant market (beef and dairy cattle) depending on relative prices of each commodity. Monogastrics (poultry and pigs) are relatively small users of barley.

Prices can be compared with historic values by consulting decile charts (Figure 21).

Global Barley Crop Calendar

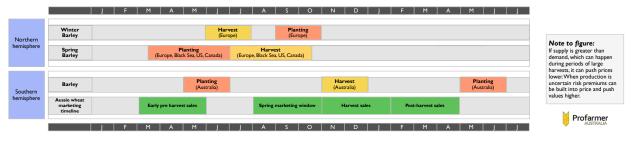
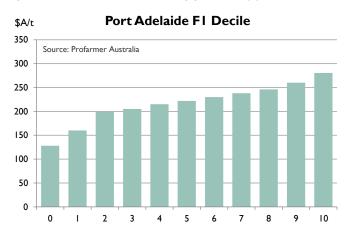
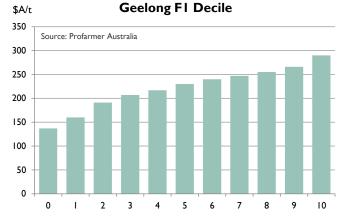


Figure 20: Seasonal factors influencing global barley prices.



Note to figure: Decile charts such as the one to the left 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.



Note to figure: Decile charts such as the one to the left 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.

Figure 21: Decile chart illustrating the price distribution for Port Adelaide and Geelong F1 barley.



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15.2.2 Ensuring market access for southern barley

Given that the majority of barley from South Australia is exported in bulk, the most cost-effective pathway to get grain to offshore customers is often 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.

Although most South Australian barley will be stored and sold from within a bulk-handling system, private commercial and on-farm storage is a reasonable alternative for accessing container export and domestic end-user markets.

In Victoria and southern New South Wales, a larger percentage of the crop will be destined for domestic markets (Table 2). Those growers who are well positioned to service domestic markets (including some parts of South Australia) can often return premiums to the bulk export market. Private commercial or on-farm storage can be a more effective method of accessing this market.

Table 2: Five-year averages for barley market destinations

	Vict	oria	South A	Nustralia	National Total		
	Implied tonnes	% of production	Implied tonnes	% of production	Implied tonnes	% of production	
Exports	0.9 Mt	40%	1.7 Mt	80%	5.0 Mt	60%	
Domestic Use	I.2 Mt	60%	0.5 Mt	20%	3.5 Mt	40%	

Source: Australian Crop Forecasters

Malt v. Feed and varietal differences and premiums

An emerging key to barley marketing is knowledge of which premiums and discounts apply for different varieties of barley. It is no longer the case that barley is simply Malt or Feed. The highly specific nature of the global malting and brewing industries means that different customers look for different traits. For example, in Port Adelaide zone in December 2015, each of Commander®, Gairdner® and Scope® (all malt varieties) are quoted at different price levels depending on the buyer or exporter, with Hindmarsh® filling a middle ground between Malt and Feed prices. New varieties such as Latrobe ® and Compass® are on the up-trend and they will also command different prices. So, knowing the varietal preferences of buyers and watching the relative values for each variety is important.

Supply-chain flow options are illustrated in Figure 22.



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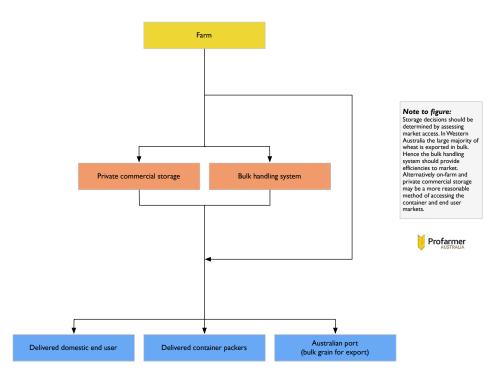


Figure 22: Australian supply-chain flow for barley.

15.2.3 Executing tonnes into cash for southern barley

Knowing where the barley crop is likely to end-up will help to refine a grower's selling and logistics decisions. Broadly, there are two customer types:

- Customer type A. These customers require consistent supply of reliable quality in regular intervals regardless of the stage of the year.
- Customer type B. These customers buy opportunistically based on price and are able to manage the quality inconsistency associated with switching suppliers more regularly.

This buyer behaviour drives the supply chain to operate at two levels. First, a consistent monthly tonnage to suit the type A customer, and secondly a surge capacity to suit the type B customer. As a result, appetite to accumulate southern barley often peaks during and shortly after harvest as the surge demand kicks in to make the most of more abundant supply, as well as cost savings by shipping immediately post-harvest (Figure 23).

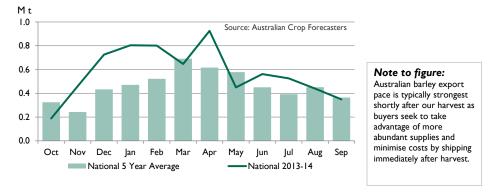


Figure 23: Monthly export pace of barley.



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What does this mean for the southern barley grower? Demand is generally strongest for southern barley during the harvest period when type A and type B customers are both active in the market; hence, the number of buyers bidding for barley increases. Because of the extra bid liquidity at harvest, most grower selling strategies should encompass some harvest sales.

The key to executing harvest sales effectively is to determine which grades to sell and which to hold. Malt 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 pre-harvest and at harvest to ensure their supply when it is available. This appetite tends to push up the price premium for malt barley grades over base F1, making them a more attractive harvest sell. These grades are higher risk to be holding for post-harvest sales as once the buyers have their requirements covered; prices tend to move toward F1 levels as buyers drop out of the market (Figure 24).

Typically, Feed barley will not perform as strongly as Malt barley. However, the gap between the two grades tends to close after harvest, making Feed barley lower risk and more desirable to hold for post-harvest sales.



Figure 24: Monthly prices of Port Adelaide Malt v. Feed barley.

15.2.4 Risk management tools available for southern barley

An Australian cash price is made up of three components: futures, foreign exchange, and basis (Figure 25). Each component affects price. A higher futures and basis and a lower exchange rate will create a higher Australian grain price.



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Several futures contracts exist including:

- ASX Eastern Australia Feed Barley: 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.

Note that liquidity in barley futures markets can be low, creating extra market risk for participants. For example, Euronext ran a European Malting Barley futures contract; however, this has been stopped owing to a lack of liquidity. Because of this, some participants choose to look at other futures markets to manage barley price risk such as CBOT wheat. Australian barley and wheat values have a high correlation; therefore, to some extent a CBOT wheat futures contract can be used to hedge price risk against barley production.

Basis (Estimated 15%) Currency A\$/US\$ (Estimated 15%) CBOT futures (Estimated 70%)

Note to figure:

Basis - The divergence in the local cash price from the futures price is known as basis. Australian cash prices will trade at a premium or discount to futures depending on local grain supply, demand and quality.

Foreign Exchange - The exchange rate impacts cash prices given most Australian canola is sold off-shore. A lower Australian dollar supports Australian prices.

CBOT futures - The futures market is the major determinant of Australian cash prices. Futures provide the opportunity for buyers and sellers to agree on a price for the sale of a commodity at an agreed time in the future. Price is influenced by anticipated supply and demand.



Figure 25: Components of pricing.

Table 3 outlines products available to manage South Australian barley prices; the major difference in products is the ability to manage the individual components of price.



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Table 3: Advantages and disadvantages of the products available to manage barley prices

Table of Contents

	Description	Advantages	Disadvantages		
Spot cash contracts	Futures, foreign	Simple to use.	Immediate grain delivery required.		
	exchange, basis all locked at time of contracting	Locks in all components of price. Cash is received almost immediately	Sales after harvest require storage which incur costs.		
	Contracting	(within payment terms).	Locks away three pricing components at the same time.		
			Risk of counterparty default between transfer and payment.		
Forward cash contracts	Futures, foreign exchange, basis all locked at time of contracting	Simple to use.	Often inflexible and difficult to exit.		
		Locks in all components of price (no uncovered price risk).	Locks away the three pricing components at the same time.		
		No storage costs.	Future delivery is required resulting in production		
		Cash income is a known ahead of	risk.		
Futures	Futuros foreign	harvest	Counterparty default risk must be managed.		
contracts	Futures, foreign exchange, basis are able to be managed individually	Liquid markets enable easy entry and exit from the marketplace.	Requires constant management and monitoring. Margin calls occur with market movements		
		Locks in only some components of price, hence more flexible than cash	creating cash-flow implications.		
		contracts.	Grain is required to offset the futures position, hence production risk exists.		
		Price determined by the market, and is completely transparent.	Cash prices may not move in line with futures, hence some price risk.		
		No counterparty risk due to daily clearing of the contracts.	You still have to sell the underlying physical grain.		
Over-the- counter bank swaps on futures contracts	Futures, foreign exchange, basis are able to be managed individually	Based off an underlying futures market so reasonable price transparency.	Costs vary between \$5-10/t at the providers discretion.		
		Liquid markets enable easy entry and	Requires constant management and monitoring.		
		exit from the marketplace. Locks in only some components of	Grain is required to offset the futures position, hence production risk exists.		
		price, hence more flexible than cash contracts.	Cash prices may not move in line with futures, hence some price risk.		
		Counter party risk is with the bank, hence it is low.	You still have to sell the underlying physical grain.		
		The bank will manage some of the complexity on behalf of the grower, including day to day margin calls.			
Options on futures contracts	Futures, foreign exchange, basis are able to be managed individually	No counterparty risk due to daily clearing of the contracts.	Options can be costly and require payment upfront.		
		No margin calls.	The value of options erode overtime as expiry		
		Protects against negative price moves	approaches - depreciating asset.		
		but can provide some exposure to positive moves if they eventuate.	Perceived to be complicated by growers.		
		Liquid markets enable easy entry and exit from the marketplace.	Move in option value may not completely offse move in cash markets. You still have to sell the underlying physical grain.		
		Price risk can be reduced without increasing production risk.			
		Price determined by the market, and is completely transparent.			



ASX: Commodities grains contract specifications

ICE: Barley futures & <u>options</u>

EURONEXT: Contract <u>list</u>

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For more information and worked examples on how each pricing component affects barley grain price, refer to the GRDC publication: Grain Market Lingo - what does it all <u>mean</u>



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A review of Research Projects supported by

the GRDC in 2013-14



SECTION 16

Current research

Project Summaries of GRDCsupported projects in 2013-14

Each year the GRDC supports several hundred research and development, and capacity building projects.

In the interests of improving awareness of these investments among growers, advisers and other stakeholders, the GRDC has assembled summaries of projects active in 2013-14.

These summaries are written by our research partners as part of the Project Specification for each project, and are intended to communicate a useful summary of the research activities for each project investment.

The review expands our existing communication products where we summarise the R&D portfolio in publications such as the Five-year Strategic Research and Development Plan, the Annual Operating Plan, the Annual Report and the Growers Report.

GRDC's project portfolio is dynamic with projects concluding and new projects commencing on a regular basis. Project Summaries are proposed to become a regular publication, available to everyone from the GRDC website.

Projects are assembled by GRDC R&D investment Theme area, as shown in the PDF documents available. For each Theme a Table of Contents of what is contained in the full PDF is also provided, so users can see a list of project titles that are covered. The GRDC investment Theme areas are:

- Meeting market requirements;
- Improving crop yield;
- Protecting your crop;
- Advancing profitable farming systems;
- · Maintaining the resource base; and
- Building skills and capacity.

The GRDC values the input and feedback it receives from its stakeholders and so would welcome your feedback on any aspect of this first review. This way we can continue to improve and extend this summary.

To send us your feedback please email us at feedback@grdc.com.au





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SECTION 17

Key contacts

Keith Pengilley (Chair)

Keith Pengilley is the general manager of a dryland and irrigated family farming operation at Conara in the northern midlands of Tasmania, operating a 7000-hectare mixed-farming operation over three properties. He is a director of Tasmanian Agricultural Producers, a grain accumulation, storage, marketing and export business. Keith is the chair of the GRDC Southern Regional Panel, which identifies and directs the GRDC's RD&E investments in the southern grains region.

M 0448 015 539

E kgpengilley@bigpond.com



Mike McLaughlin (Deputy chair)

Based in Adelaide, Mike McLaughlin is a researcher with the University of Adelaide and CSIRO at the Waite campus. He specialises in soil fertility and crop nutrition, as well as contaminants in fertilisers, wastes, soils and crops. Mike manages the Fertiliser Technology Research Centre at the University of Adelaide and has a wide network of contacts and collaborators nationally and internationally in the fertiliser industry and in soil fertility research.

M 0409 693 906

E michael.mclaughlin@adelaide.edu.au or mike.mclaughlin@csiro.au



John Bennett

Based at Lawloit, between Nhill and Kaniva in Victoria's west Wimmera, John Bennett and his wife, Allison, run a mixedfarming operation across diverse soil types. The farming system is 70 to 80 per cent cropping, with cereals, oilseeds, legumes and hay grown. John serves on the GRDC High-Rainfall Zone Regional Cropping Solutions Network and the Birchip Cropping Group Wimmera Advisory Committee. John has a strong desire to see the agricultural sector promoted as an exciting career path for young people and to see R&D investments promote resilient and sustainable farming systems that ultimately deliver more profit to the grower.

M 0429 919 223

E john.bennett5@bigpond.com





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Peter Kuhlmann

Peter Kuhlmann is a grower at Mudamuckla near Ceduna on SA's western Eyre Peninsula. He uses liquid fertiliser, no-till and variable-rate technology to assist in the challenge of dealing with low rainfall and subsoil constraints. He has been a board member and chaired the Eyre Peninsula Agricultural Research Foundation and the South Australian Grain Industry Trust. In 2012 Peter won the ABC Rural and Kondinin Group Australian Farmer of the Year award.



M 0428 258 032

E mudabie@bigpond.com

Bill Long

Bill Long is an agricultural consultant and grower on SA's Yorke Peninsula. He has led and been involved in many RD&E programs and was one of the founding members of the Yorke Peninsula Alkaline Soils Group and is a former chair of Ag Excellence Alliance. He has a strong interest and involvement in farm business management and communication programs within the GRDC. He is a Churchill Fellow.



E bill@agconsulting.com.au



Jon Midwood

Jon Midwood has worked in agriculture for the past 28 years, both in the UK and Australia. He graduated from Harper Adams University in the UK and then spent 13 years working for a large UK farm management company. In 2004 he moved to Geelong, Victoria, and managed Grainsearch, a grower-funded company evaluating European wheat and barley varieties for the high-rainfall zone. Jon set up his own consulting business in 2007, which included managing the commercial contract trials for Southern Farming Systems (SFS). In 2010 he became chief executive of SFS, one of the largest farming systems groups in the southern region with five branches covering southern Victoria



(Gippsland and the western district) and Tasmania. In 2012, Jon became one of the initial members of the HRZ Regional Cropping Solutions Network set up by the GRDC. M 0400 666 434

E jmidwood@sfs.org.au

Rohan Mott

A fourth-generation grain grower at Turriff in the Victorian Mallee, Rohan Mott has been farming for 24 years and is a director of Mott Ag. With significant on-farm storage investment, Mott Ag produces wheat, barley, lupins, field peas, lentils and vetch, including vetch hay. Rohan continually strives to broaden his understanding and knowledge of agriculture, is passionate about the sustainability of Australian agriculture, and has a keen interest in new technology and value-adding.



E rohanmott@gmail.com







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Rob Sonogan

From Swan Hill in north-west Victoria, Rob Sonogan is an extension agronomist who has specialised within government agencies in the areas of soil conservation, resource conservation and dryland farming systems. Over three decades he has been privileged to have had access to many growers, businesses, consultants, rural industry and agribusiness advisers. Rob also has been closely involved in rural recovery and emergency response into issues as diverse as locusts, fire, mice, flood and drought. Rob is employed part-time within the Mallee consultancy group AGRIvision Consultants. M 0407 359 982



E sonoganrob@gmail.com

Mark Stanley

Mark Stanley comes from a mixed-farming background and has had extensive experience in field crops development and extension and in natural resources management within state and Australian governments and with industry. He operates his own project-management business, Regional Connections, on SA's Eyre Peninsula. Mark leads a large carbon farming outreach and extension project with the Australian Department of Agriculture, and provides executive leadership to Ag Excellence Alliance, supporting farming groups across SA. He is on the board of the Eyre Peninsula Agricultural Research Foundation and is a committee member of the Lower Eyre Agricultural Development Association.



M 0427 831 151

E mark@regionalconnections.com.au

Kate Wilson

Kate Wilson is a partner in a large grain operation in Victoria's southern Mallee region. Kate's husband, Grant, is a third-generation grower in the area and, with their two children, they grow wheat, canola, lentils, lupins and field peas. Kate has been an agronomic consultant for more than 20 years, servicing clients throughout the Mallee and northern Wimmera. Kate is passionate about growing high-quality grain, while enhancing the natural ability of the soil to do so. Having witnessed and implemented



much change in farming practices over the past two decades, Kate is also passionate about research and the extension of that research to bring about positive practice change to growers.

M 0427 571 360

E kate.wilson@agrivision.net.au



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Tanya Howitt

Tanya Howitt joined the GRDC in August 2014 as the executive manager of corporate services, coming from the Australian Fisheries Management Authority where she held two roles over her time there – chief finance officer and general manager corporate. The aim of corporate services is to be the enabler for the GRDC's services and products for stakeholders. Corporate services plays a key role in the GRDC: improving systems and processes, to simplify and automate where possible and to enhance the GRDC's ability to respond to stakeholder requirements.



T 02 6166 4500

E tanya.howitt@grdc.com.au

Rebecca Jeisman (Panel support)

Rebecca Jeisman works for AgCommunicators, specialising in communication and education for primary production, science and natural resources. Rebecca provides meeting, communication, project and event support to the Southern Panel. M 0438 683 436

E rebeccaj@agcommunicators.com.au





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SECTION 18

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