



# GRDC

≡ GROWNOTES® ≡

*Know more. Grow more.*

# Wheat

Southern Region

February 2016

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

**GRDC**

Grains Research &  
Development Corporation  
Your GRDC working with you

# Start here for answers to your immediate wheat crop management issues

**What variety should I grow?**



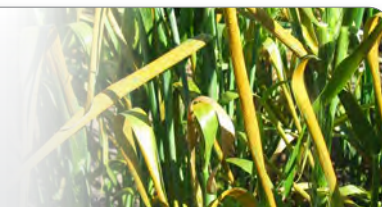
**What's the latest thinking on frost management in 2016?**



**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 wheat production

Removing volunteer cereal hosts and other **'green bridge'** weeds at least

**4 WEEKS**

before sowing reduces pathogen spore loads in subsequent wheat crops

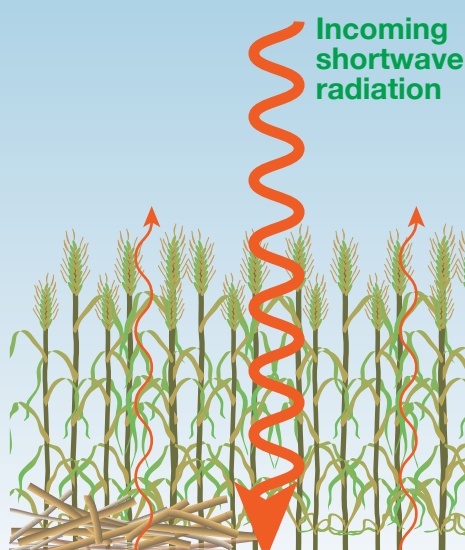
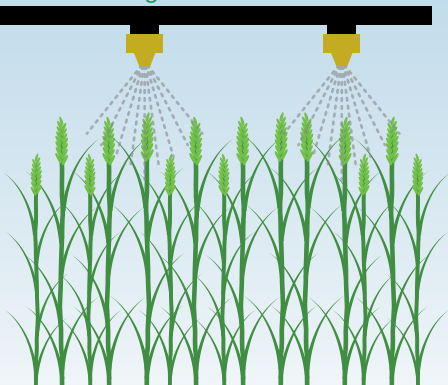
Be ruthless with **WEED SEED CONTROL** to manage herbicide resistance.

Timing of wheat planting is critical  
**HIGH SOIL TEMPERATURES CAN REDUCE ESTABLISHMENT**



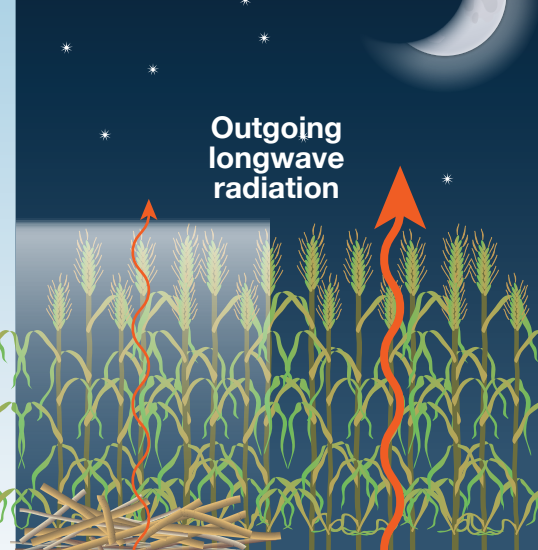
The ideal temperature range for wheat germination is, **12°-25°C** but germination will occur between **4°C AND 37°C**

It is more effective to use fungicides to **PROTECT A CROP FROM RUST INFECTION** rather than to control an already occurring rust outbreak



Less heat stored

More heat stored



Less heat released

More heat released

10cm

10cm

Soil captures heat during the day and radiates it into the crop canopy overnight to **WARM FLOWERING HEADS AND MINIMISE FROST DAMAGE.** See the **LATEST FROST TIPS FOR 2016** for how to modify the soil heat bank

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## SECTION A

## Introduction

 More information

[Australian Bureau of Agricultural and Resource Economics and Sciences](#)

[Bureau of Meteorology: Climate data online](#)

## A.1 Production

Australian wheat farmers produce ~16 million tonnes (Mt) of wheat each year, 70% of which is exported. In world terms, Australia is the fourth largest exporter, contributing ~11% of world trade.

Asia, the Middle East and the Pacific regions are the principal export destinations. The domestic market is the largest single market and it is growing rapidly.<sup>1</sup>

The national gross value of wheat increased by 12% from 2012–13 to 2013–14, reflecting strong domestic demand and increased production, particularly in South Australia.

In Victoria, wheat production in 2013–14 was valued at AU\$1,105.9 million, a significant increase on the 2006–07 season, which produced wheat worth \$209.1 million. Recent production figures include 4.4 Mt produced from 1.8 million hectares (Mha) in 2011 (Figure 1).

In 2011, South Australia produced close to 6 Mt from 2.36 Mha, and Tasmania produced 31,900 t from 8100 ha.<sup>2</sup>

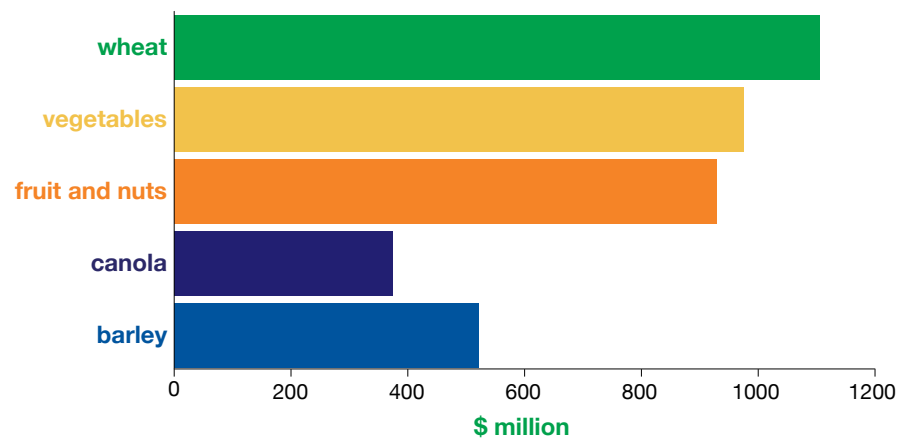


Figure 1: Gross value of wheat production in Victoria compared with other grain and horticulture crops, 2013–14. (Source: Australian Bureau of Statistics)<sup>3</sup>

<sup>1</sup> ABS (2015) 7121.0. Agricultural commodities, Australia, 2013–14. Australian Bureau of Statistics, <http://www.abs.gov.au/ausstats/abs@.nsf/mf/7121.0>

<sup>2</sup> ABS (2013) 7124.0. Historical selected agriculture commodities, by state (1861 to present, 2010–11). Australian Bureau of Statistics, <http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/7124.0Chapter72010-11>

<sup>3</sup> ABS (2015) 7503.0. Value of agricultural commodities produced, Australia, 2013–14. Australian Bureau of Statistics, <http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/7503.0>



## SECTION 1

# Planning/Paddock preparation

Profitable growing of winter crops demands higher production per unit area while aiming to maintain a low cost per unit of production. This can only be achieved by increasing grain yields through economic adoption of new or improved technology. The aim is not only higher total production, but also greater productivity from the resources invested in crop production, along with total sustainability of the farm business.

Check out what other Southern Region growers are doing at <http://grdc.com.au/Media-Centre/Over-the-Fence/Over-The-Fence-Videos/Over-the-Fence-Southern-Region> and keep up to date with the latest news at <http://grdc.com.au/Media-Centre/Ground-Cover>, <http://grdc.com.au/Media-Centre/GRDC-Podcasts/Driving-Agronomy-Podcasts> and <http://www.grdc.com.au/Media-Centre/GroundCover-TV>.

## 1.1 Paddock selection

Pulses, oilseeds, oats and barley offer breaks crops for many wheat diseases, and indeed, differing genetic backgrounds of wheat varieties sometimes allow wheat to be sown in consecutive years. Incorporation of disease resistances and tolerances into wheat has also virtually eliminated some diseases, such as cereal cyst nematode, and allowed more frequent sowing of wheat.

Choice of paddock to sow wheat is therefore based on a range of issues. Economics, production risk from disease or weed pressures, herbicide residues, seasonal forecasts, stored soil water, and achieving a balance of risk with other crop types are some of the considerations.<sup>1</sup>

Profitable wheat yields result from good management, of which variety choice is only one component. Managing soil moisture, disease, weed and nutrients are also important.

Paddock selection and rotation, combined with use of disease-resistant varieties, are the best actions to minimise disease (Figure 1).<sup>2</sup>

<sup>1</sup> Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

<sup>2</sup> NSW DPI District Agronomists (20082007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

## More information

[GRDC Update Papers: Management of yellow spot in wheat: decide before you sow](#)

[GRDC Resources: IWM Hub. Section 2 – Agronomy to enhance weed management](#)



Figure 1: Paddock selection and rotation combined with use of disease-resistant varieties are the best actions to minimise disease. (Photo: Penny Heuston)

### 1.1.1 Paddock topography

Topographical characteristics can determine crop and pasture options (Figure 2). Crops and varieties prone to lodging should be avoided in uneven paddocks. Waterlogged conditions also reduce root growth and can predispose the plant to root rots.<sup>3</sup> Choose varieties with higher tolerance to wet conditions.



Figure 2: Topographical characteristics can determine crop options. (Photo: Penny Heuston)

<sup>3</sup> J Ransom (2011) Impacts of flooding/waterlogging on crop development. North Dakota State University Crop & Pest Report (, 26 May 2011), <http://www.ag.ndsu.edu/cpr/plant-science/impacts-of-flooding-waterlogging-on-crop-development-5-26-11>

## More information

[http://www.ag.ndsu.edu/cpr/plant-science/impacts-of-flooding-waterlogging-on-crop-development-5-26-11 - no link?NDSU: Impacts of flooding/waterlogging on crop development](http://www.ag.ndsu.edu/cpr/plant-science/impacts-of-flooding-waterlogging-on-crop-development-5-26-11-no-link?NDSU:Impacts%20of%20flooding/waterlogging%20on%20crop%20development)

## More information

[NSW DPI: Weed control in winter crops](#)

[GRDC Ground Cover: Weeds don't like the competition](#)

## More information

[GRDC Update Papers: Diseases shared by different crops and issues for crop sequencing](#)

### 1.1.2 Soil type

Soil characteristics (surface and subsurface) such as pH, sodicity, salinity, acidity, texture, drainage characteristics and compaction will affect variety selection. See the National Variety Trials (NVT) guides for details of recommended varieties and planting times for individual districts within the Southern Region. For more detail, see [GrowNotes Wheat South. Section 2. Pre-planting.](#)

### 1.1.3 Subsoil moisture

Growing a crop always incurs financial risk due to upfront expenditure on inputs, labour and fuel. Low levels of available soil moisture at sowing can significantly increase financial risks. Paddocks with retained stubble can retain moisture for longer, extending the time for planting after small rainfall events. Levels of starting available soil moisture should also affect crop variety choice. Varieties with greater canopy size, such as late-maturing and/or very vegetative varieties, will generally require higher soil moisture levels to perform well.

### 1.1.4 Paddock nutrition

Fertiliser can be a major upfront investment. Fertiliser rates to meet crop requirements may be modified if residual fertiliser from the last season remains. Soil tests, paddock history, past crop performance and fertiliser test strips can help to determine the most appropriate decision. Paddocks often have multiple nutrition deficiencies or variations in nutritional requirements, even with a similar cropping history.

### 1.1.5 Herbicide history

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonylurea, triazines, etc.) may be an issue in some paddocks. Remember that plant-back periods begin after significant rainfall occurs. For more information, see under heading below 'Fallow chemical plant-back periods' and download the NSW DPI publication [Weed control in winter crops.](#)

### 1.1.6 Weed burden

A high weed burden will influence the likelihood of cropping success. The species present or likely to occur based on previous years should influence crop species choice to ensure that effective in-crop control measures are available.

Strategic and integrated weed management over a rotation can greatly increase the likelihood of controlling weeds across all crops. Paddocks being planted to wheat in the first year of rotation should for instance have a vigilant strategy for the control and prevention of seed set of key broadleaf weeds prior to a rotation to canola or legume crops.

The use of pre-emergent herbicides as appropriate should be considered as well as cultural control methods such as species choice and row width.

### 1.1.7 Disease carryover

Crop sequencing and rotation are important components of long-term farming systems and contribute to the management of soil nitrogen status, weeds, pests and diseases.

In the paddock, considerations include soil moisture levels before planting, current and desired stubble cover, and history of herbicide use and history of diseases.

Crop sequencing is only a part of the integrated management of diseases. Other practices include maintaining sufficient distance from last year's paddock of the same crop or from a paddock with residue infected with a pathogen of the intended crop; the use of high-quality, fungicide-treated seed; planting within the planting window, variety selection, and in-crop fungicide treatments. <sup>4</sup>

<sup>4</sup> M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers, 13 September 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Diseases-shared-by-different-crops-and-issues-for-crop-sequencing>

The previous crop will influence levels of both soil- and residue-borne diseases. Important diseases to consider include take-all, crown rot, yellow leaf spot, stripe rust, cereal cyst nematode, and wheat streak mosaic virus. Transmission from neighbouring paddocks and volunteers are key concerns with some diseases. Controlling the 'green bridge' of over-summering cereals and weeds is an important strategy.

### 1.1.8 Pests

Pests such as redlegged earth mites, blue oat mites, nematodes and, in some seasons, cutworms pose a risk in some paddocks. Risk should be assessed based on paddock history (including recent control) and crop susceptibility. Controlling weeds in summer fallows and around paddocks can also minimise some of these pests.

For information on in-furrow treatment options see [GrowNotes Wheat South Section 3. Planting](#).

See also [GrowNotes Wheat South Section 7. Insect control](#).

Further information is available from the Australian Pesticides and Veterinary Medicines Authority Public Chemical Registration Information System ([APVMA PubCRIS](#) database) and winter crop variety sowing guide websites.

### 1.1.9 Fallow management

Paddocks with well-managed fallow periods significantly lower the risk of poor crop and financial performance.

Timely weed control can reduce moisture and nutrition loss, prevent an increase in the seedbank, and decrease the risk of disease carryover. Absence (or restriction) of grazing periods maintains soil friability and groundcover. Prolonged grazing periods may create crop emergence problems through induced surface compaction.<sup>5</sup> (See *under heading Fallow weed control below*.)

The green bridge provides a between-season host for insects and diseases (particularly rusts); these pose a threat to future crops and can be expensive to control later in the season.

Key points for control of the green bridge:

- Outright kill of the weeds and volunteers is the only certain way to stop them from hosting diseases and insects.
- Diseases and insects can quickly spread from the green bridge, jeopardising crops and current control methods, including the effectiveness of chemicals and genetic breeding for resistance.
- Effective control of pest and disease risks requires neighbours to work together to eradicate weeds and crop volunteers simultaneously.
- Weed growth during summer and autumn depletes soil moisture and nutrients that would otherwise be available to following crops and can have an allelopathic effect.<sup>6</sup>

The GRDC produces an annual [Paddock Diary](#) for downloading, which includes information and record-keeping templates.

Diary headings include:

- Your paddocks list
- Paddock operations and paddock observations
- Growth stages
- Pests, diseases and weeds

<sup>5</sup> N Border, K Hertel, P Barker (2007) Paddock selection after drought. NSW Department of Primary Industries, February 2007, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0010/126100/paddock-selection-after-drought.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0010/126100/paddock-selection-after-drought.pdf)

<sup>6</sup> GRDC (2009) Green bridge—The essential crop management tool —green bridge control is integral to pest and disease management. Green Bridge Fact Sheet, GRDC Fact Sheet, [http://www.grdc.com.au/uploads/documents/GRDC\\_GreenBridge\\_FS\\_6pp.pdf](http://www.grdc.com.au/uploads/documents/GRDC_GreenBridge_FS_6pp.pdf)

## More information

[APVMA: Public Chemical Registration Information System search](#)

## More information

[GRDC Fact Sheets: The essential crop management tool—green bridge control is essential to pest and disease management](#)

[NSW DPI: Paddock selection after drought](#)

## More information

[GRDC Ground Cover: Paddock Diary 2015](#)

## More information

[Ag Excellence Alliance: Cover cropping benefits from the Mallee](#)

[Research paper: Warm season cropping in the southern cropping zone of Australia](#)

[Farm Weekly: Cover cropping demo grows](#)

[Nuffield Farming Scholars: David Cook](#)

[Aust Cover Crop: David Cook, Nuffield Scholar](#)

[Weekly Times: New tillage radish to revolutionise cropping](#)

[Victorian No-till Farmers Association](#)

- Rust risk
- The Australian Cereal Rust Control Program
- Groups (modes of action)
- Herbicide resistance
- How will you spray this year?
- Spray application
- Surface temperature inversions and spraying
- Delta T and droplet survival
- Spray calibration
- Nozzle selection and calculation
- Sprayer checks and calibration
- Pesticide application
- Water-use efficiency (WUE)
- Planting rate
- Rainfall records
- Calendars
- Public holidays and school terms
- Names and addresses
- Weights and measures
- Conversions formulae
- Useful conversions

### **Fallow moisture**

A growing crop has two sources of water: the water stored in the soil during the fallow, and the water that falls as rain while the crop is growing. Growers have some control over the stored soil water; measure soil water before planting the crop. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when needed. <sup>7</sup>



<sup>7</sup> J Whish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Papers, 23 July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW>

## **i** More information

[GRDC Ground Cover: Returns from break crops can challenge wheat](#)

[GRDC Fact Sheets: Choosing rotation crops. Short-term profits, long-term payback](#)

[GRDC: Improving productivity by rotating wheat varieties in wheat on wheat systems](#)

[GRDC Update Papers: Drivers of profit and success—use of technology on the farm](#)

[GRDC: Integrated disease management for cereal and broadleaf crops in southern NSW and northern Victoria](#)

[GRDC Update Papers: Crop and pasture sequences sustain wheat productivity](#)

[GRDC Update Papers: Crop sequencing—what are the key issues to making profitable and sustainable decisions?](#)

[CSU: Crop sequences: using broadleaf crops to improve wheat grain production and profitability](#)

[FAO: What is the best cropping sequence for the farm?](#)

[Research paper: Break crops pay in the Victorian Mallee](#)

[GRDC Online Farm Trials: Barley and wheat disease management using foliar and fertiliser fungicides](#)

[GRDC Ground Cover: Crop sequencing supplement](#)

## 1.2 Paddock rotation and history

Paddock choice can determine the amount of disease, weed and nutrient pressure on the crop. Increasing interest in crop sequencing is providing more financial and agronomic data to help growers to choose crops and paddocks each year.

### 1.2.1 Benefits of cereals as a rotation crop

Cereals present the opportunity for effective utilisation of residual N. They also offer good options for broadleaf control and are non-hosts for many pulse crop and oilseed diseases. A major benefit of winter cereal crops is the high levels of groundcover they provide for management of soil loss in following fallows and some subsequent pulse crops.

### 1.2.2 Disadvantages of cereals

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, tan (yellow) spot, nematodes
- nitrogen (N) depletion and declining soil fertility

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

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

A broadleaf crop is often included in the crop sequence to counteract limitations in the cereal phase (weeds, disease, N), so the broadleaf crop's financial impact may be considerably better if considered across the crop sequence.<sup>8</sup>

Leading growers and advisers advocate sustainable crop sequences as a valuable strategy for southern farming systems. Many growers are sacrificing cereal yield and protein by not adopting current research findings on the use of correct sequences.<sup>9</sup>

Modern conservation cropping systems sometimes involve successive wheat, no-till crops, which can suffer 5–15% yield penalties from unidentified biological constraints in the rhizosphere. However, evidence from field and laboratory studies shows that some wheat varieties perform better in these conditions, owing to differences in the chemistry of root exudates or residues, which influence rhizobacterial populations. Varietal differences also interact with soil type, season and agronomic management (sowing time, row placement).

CSIRO researchers have developed hypotheses that may explain these effects. They aim to establish which selected wheat varieties perform better in intensive wheat rotations and to improve industry understanding of the mechanisms involved. These steps are necessary to capitalise on the significant increase in productivity for the grains

<sup>8</sup> 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>

<sup>9</sup> GRDC (2011) Choosing rotation crops—Short-term profits, long-term payback. GRDC Fact Sheet Northern Region. Choosing Rotation Crops Fact Sheet, GRDC, March 2011, [http://www.grdc.com.au/~media/9219D55FFB4241DC9856D6B4C2D60569.pdf](http://www.grdc.com.au/~/media/9219D55FFB4241DC9856D6B4C2D60569.pdf)

## **i** More information

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

<http://www.agronomy2015.com.au/papers/agronomy2015final00155.pdf>

Research paper: [Effects of row spacing and row placement on grain yield in a sorghum/wheat sequence under high rainfall](#)

## **i** More information

GRDC Online Farm Trials: [Sick crops in the southern Mallee in 1995](#)

Research paper: [Increasing mycorrhizal colonisation does not improve growth and nutrition of wheat on Vertosols in south-eastern Australia](#)

Research paper: [Rotation, sequence and phase. Research on crop and pasture systems](#)

Farming Ahead: [Mycorrhizal fungi enhance crop nutrient uptake](#)

Research paper: [Is there a role for arbuscular mycorrhizal fungi in production agriculture?](#)

industry that would arise from breeding and/or agronomic strategies to overcome the productivity constraints in intensive cereal systems.<sup>10</sup>

### 1.2.3 Long-fallow disorder

Soils naturally contain beneficial fungi that help the crop to access nutrients such as phosphorus (P) and zinc (Zn). The combination of the fungus and crop root is known as arbuscular mycorrhiza(e) (AM) (Figure 3). Many different species of fungi can have this association with the roots of crops. Many that are associated with crops also form structures called vesicles in the roots.

The severe reduction or lack of AM shows up as long-fallow disorder—the failure of crops to thrive despite adequate moisture. Ongoing drought in the 1990s and beyond has highlighted long-fallow disorder where AM have died out through lack of host plant roots during long periods of fallow. As cropping programs restart after dry years, an unexpected yield drop is likely due to reduced AM levels, making it difficult for the crop to access nutrients.

Long-fallow disorder is typified by poor crop growth. Plants seem to remain in their seedling stages for weeks and development is very slow.

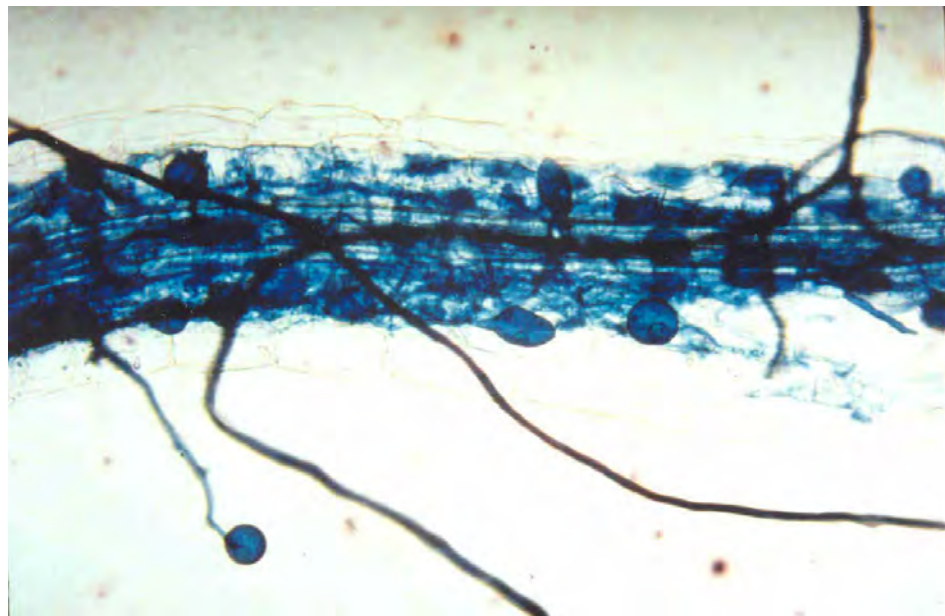


Figure 3: Arbuscular mycorrhizae pictured in a wheat root. (Photo: DAF Qld)

Benefits of good levels of AM are:

- improved uptake of P and Zn
- improved crop growth
- improved N<sub>2</sub> fixation
- greater drought tolerance
- improved soil structure
- greater disease tolerance

<sup>10</sup> J Kirkegaard (2008) Improving productivity by rotating wheat varieties in wheat on wheat systems. GRDC Research & Development Project CSP00115, <http://www.grdc.com.au/Research-and-Development/Meeting-market-requirements/CSP00115>

In general, the benefits of AM are greater at lower soil P levels because AM increase a plant's ability to access this nutrient. Crops with higher P dependency benefit more from AM (Table 1).<sup>11</sup>

Table 1: Dependency of various crop species on mycorrhizae (value decreases as the phosphorus level of the soil increases)

Mycorrhizal dependency	Potential yield loss without mycorrhizae (%)	Crops
Very high	>90	Linseed
High	60–80	Sunflowers, mungbeans, pigeon peas, maize, chickpeas
Medium	40–60	Sudan grass, sorghum, soybeans
Low	10–30	Wheat, barley, triticale
Very low	0–10	Panicum, canary grass
Nil	0	Canola, lupins

## More information

[GRDC Fact Sheets: Summer fallow spraying](#)

[GRDC Update Papers: Achieving good pre-emergent spray results](#)

[GRDC Update Papers: Summer weeds reduce moisture and nitrogen](#)

[GRDC Update Papers: Impact of crop residues on summer fallow weeds](#)

[GRDC: Manual summer fallow weed management](#)

## 1.3 Fallow weed control

Paddocks generally have multiple weed species present at the same time, making weed-control decisions more difficult and often involving 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 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.<sup>12</sup>

### 1.3.1 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.<sup>13</sup>

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. For a double knock with herbicides to be successful both applications should be at label rate for control.

<sup>11</sup> DAFF DAF Qld (2010) Nutrition—VAM and long fallow disorder. Department of Agriculture, and Fisheries and Forestry Queensland, 14 Sept. 2010, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam>

<sup>12</sup> GRDC (2012) Summer fallow—Make summer weed control a priority. GRDCWestern Region Summer Fallow Management Fact Sheet GRDC, January 2012., <http://www.grdc.com.au/-/media/91deacef2dd843f6bbf9fab09bfe0d65.pdf>

<sup>13</sup> C Borger, V Stewart, A Storrie. DAFWA. Herbicides—knockdown herbicides for fallow and pre-sowing control. Department of Agriculture and Food, Western Australia, <https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C1>



## More information

[GRDC: Weed Webinars](#)

[GRDC: Integrated Weed Management Hub](#)

Double-knock strategies are not fail-proof and are rarely effective for salvage weed-control situations unless environmental conditions are exceptionally favourable.

## 1.4 Fallow chemical plant-back periods

Plant-back periods are the 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 or carryover 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 2. Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the SUs. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops, etc.' heading in the 'General Instructions' section of the label.<sup>14</sup>

Table 2: Residual persistence of common pre-emergent herbicides and noted residual persistence from broadacre trials and paddock experiences<sup>15</sup>

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://www.cdpr.ca.gov/>

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®

<sup>14</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf)

<sup>15</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf)

## More information

[Australian Pesticides and Veterinary Medicines Authority](#)

[NSW DPI: Using pre-emergent herbicides in conservation farming systems](#)

[NSW DPI: Weed control winter crops](#)

### 1.4.1 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.

Both processes are enhanced by heat and moisture. However, they are both impeded by herbicides binding to the soil, and this depends upon 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.

### 1.4.2 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. Read the herbicide label.

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

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

Be wary of compounding a residue problem by planting a herbicide-resistant crop and spraying with more of the same herbicide group. You may avoid the problem with residues in the short term however be further locked out for future 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)

There is still debate 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)

The imidazolinones are very different from the 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. 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.

### 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.

### 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

Coppyralid 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.

2,4-D used 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.<sup>16</sup>

#### 1.4.3 Genetic controls

The Clearfield® Production System is designed to deliver extended weed control and increased yield potential and crop quality.<sup>17</sup> It matches selected seed varieties with Intervix®, a custom-designed herbicide that can only be used on Clearfield® varieties. Refer to the herbicide label for weed species that can be controlled.

## 1.5 Seedbed requirements

Wheat seed needs good soil contact for germination (Figure 4). This can be assisted with press-wheels, coil packers or rollers. Soil type determines which implement will produce the ideal seedbed.

If germination rate and vigour are good, 70–90% of seeds sown will produce a plant. Depth of sowing, disease, crusting, moisture and other stress in the seedbed all reduce

<sup>16</sup> <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>

<sup>17</sup> Crop Care (2011) Clearfield best management practice. Crop Care Australasia Pty Ltd, <http://www.cropcare.com.au/Assets/501/1/2011ClearfieldBMPWeb.pdf>

#### More information

[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](#)

#### More information

[BASF: Clearfield Production System](#)

#### Video

[Stubble height and crop emergence](#)

## **i** More information

[GRDC Update Papers: Riverine Plains Inc. research update](#)

[Corangamite CMA: Brown Book—how to optimise your soils to enhance productivity](#)

[GRDC Update Papers: Using crop competition for weed control in barley and wheat](#)

[Research paper: Variations in wheat yields behind windbreaks in southern Queensland](#)

[Research paper: Small grains seedbed preparation and residue management](#)

## **i** More information

[GRDC Update Papers: Wheat variety response to dry sowing and seeding depth](#)

[GRDC Update Papers: Row spacing and deep sowing](#)

[Research paper: Effect of sowing depth on the establishment of several commercial wheat varieties](#)

[Riverine Plains: Sowing date—getting the best from our varieties and optimising whole-farm wheat yield](#)

## **i** More information

[NSW DPI: Coleoptile length of wheat varieties](#)

the number of plants establishing. Field establishment is unlikely to be above 90%, and may be as low as 60% if seedbed conditions are unfavourable.

Seedbed preparation is also important to emergence. A cloddy seedbed may reduce emergence because the clods allow light to penetrate below the soil surface. The coleoptile senses the light and stops growing while still below the surface.<sup>18</sup>

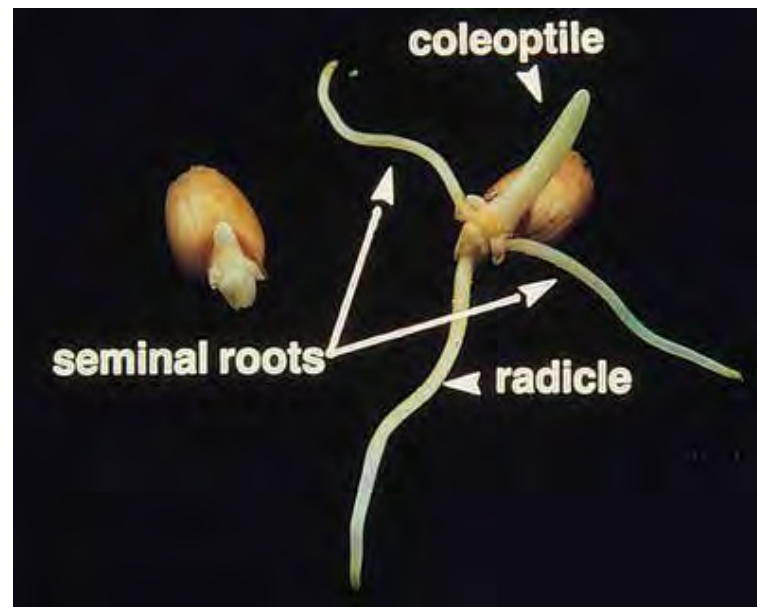


Figure 4: Germinated wheat seed. (Photo: David L. Hansen, University of Minnesota)

### 1.5.1 Deep sowing

For successful crop establishment, seed needs to be placed into soil with enough seedbed moisture for germination to occur, or into dry soil in anticipation of rainfall to increase soil moisture levels such that germination may occur.

Where soil profiles have high levels of plant-available water in the root-zone coupled with a dry seedbed, 'moisture seeking' may be required. The seed is placed deeper in the soil than is generally recommended, with the aim of ensuring timely crop establishment. This practice generally involves the use of tynes to open a furrow to a depth of >7.5 cm, into which the seed is then placed, followed by a press-wheel to close moist soil around the seed. Moisture seeking is reported to increase cropping frequency and improve timeliness of crop establishment.

### 1.5.2 Coleoptile length

Most wheat varieties currently grown in Australia contain a reduced-height gene that results in shorter plants and shorter coleoptiles than standard-height varieties. A positive correlation has been found between coleoptile length and crop establishment, which implies that widely grown, semi-dwarf varieties have reduced establishment compared with standard-height varieties when sown deep.

<sup>18</sup> NSW DPI District Agronomists (2008) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries 2007, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0006/449367/Proccrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/449367/Proccrop-wheat-growth-and-development.pdf)

## **i** More information

[GRDC Update Papers: New technology for measuring and advising on soil water](#)

[GRDC: Making the most of a wet summer in the Southern Region](#)

[GRDC Update Papers: Dune discharge seepage areas in the South Australian landscape](#)

[GRDC Update Papers: Dryland water-use efficiency – what is it and how to improve it](#)

## **i** More information

[GRDC: Estimating plant-available water capacity](#)

[GRDC Update Papers: Moisture probes – application and usefulness in crop decision making](#)

[GRDC Update Papers: Managing seasonal variability with soil moisture monitoring devices](#)

## 1.6 Soil moisture

### 1.6.1 Dryland

Water availability is a key limiting factor for wheat production in the grainbelt of Australia. Varieties with improved adaptation to water-limited conditions are actively sought and studies have been carried out to identify the physiological basis of the adaptive traits underpinning this advantage. Experiments were undertaken in field environments representing the range of moisture availability conditions commonly encountered by winter crops grown on deep Vertosol soils.<sup>19</sup>

#### *Technologies to support decision-making*

Several technologies will provide a level of information useful in decision-support without excessive investment.

#### *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. 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 achieve confidence in results. This comes at an increased capital cost.

Some devices (capacitance sensors, time-domain reflectometers) also have an upper measurement limit over which they are unable to measure soil water accurately. This may be a problem 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. The 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. However, it is unsuitable for use in saline soils and does not apportion soil water to particular layers within the soil profile.<sup>20</sup>

#### *The EM38*

Despite the extensive range of monitoring instruments now available, measuring paddock soil moisture remains a challenge. Among the suite of instruments on offer, 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 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. Both relate well to crop yield. It is also used widely in agronomic and environmental applications to monitor soil water within the root-zone. The EM38 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, such as the application, timing and conservation of irrigation water and fertiliser. EM38

<sup>19</sup> JT Christopher, AM Manschadi, GL Hammer, AK Borrell (2008) Developmental and physiological traits associated with high yield and stay-green phenotype in wheat. *Australian Journal of Agricultural Research* 59, 354–364., <http://www.publish.csiro.au/paper/AR07193.htm>

<sup>20</sup> N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Papers Goondiwindi, 5 March 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water>

## More information

[GRDC Update Papers: A 'how to' for getting soil water from your EM38 field measurements](#)

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-how-to-for-getting-soil-water-from-your-EM38-field-measurements>

## More information

[GRDC Update Papers: New technology for measuring and advising on soil water](#)

## More information

[GRDC Update Papers: Subsoil constraints: impacts of crop type, variety and agronomy on crop performance](#)

datasets have also proved valuable to test and validate water balance models that are used to extrapolate to other seasons, management scenarios and locations.

The 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. This information is vital to farm-management decisions based on accurate knowledge of soil PAW.<sup>21</sup>

### *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 the device output signal to gravimetric or volumetric water content.

To calculate the availability of soil moisture for crop use (mm 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, to make reasonable assumptions on values for drained upper limit and crop lower limit. An alternative is [Soil Water Express](#), a tool that uses the soil's texture, salinity and bulk density to predict PAWC and convert electronic sensor output to meaningful soil-water information (mm available water).<sup>22</sup>

### *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 with 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](#) (Agricultural Production Systems Simulator) and [Yield Prophet](#)<sup>®</sup> successfully predict soil water and they should be considered for both fallow and cropping situations. [ClimMate](#) is a good choice for managing fallow water.<sup>23</sup>

### *Subsoil constraints*

Soils with high levels of chloride and/or sodium in their subsurface layers are often referred to as having subsoil constraints. There is growing evidence that these constraints affect wheat yields by increasing the lower limit of a crop's available soil water and thus reducing the soil's PAWC.<sup>24</sup>

### *Effect of strategic tillage*

Research showed that one-time tillage with a chisel plough or an offset disc in long-term no-tillage 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 after tillage, prior to seeding in these years.

<sup>21</sup> J Foley (2013) A 'how to' for getting soil water from your EM38 field measurements. GRDC Update Papers Goondiwindi, 5 March 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-how-to-for-getting-soil-water-from-your-EM38-field-measurements>

<sup>22</sup> L Burk, N Dalgliesh (2012) Soil Water Express—a system to generate approximate soil water characterisations and current soil water estimates from minimal input data. 16th Australian Agronomy Conference 2012, [http://www.regional.org.au/au/asa/2012/soil-water-management/8164\\_dalgleishn.htm](http://www.regional.org.au/au/asa/2012/soil-water-management/8164_dalgleishn.htm)

<sup>23</sup> N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Papers Goondiwindi, 5 March 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water>

<sup>24</sup> 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>

## **i** More information

[GRDC Update Papers: The strategic use of tillage in conservation farming](#)

[GRDC Fact Sheets: Is there room for strategic tillage in a no-till system?](#)

[GRDC Update Papers: Tillage impact in long-term no-till](#)

## **▶** Video

[Strategic tillage](#)

## **i** More information

[GRDC Update Papers: Finley irrigated wheat, canola and faba bean systems results 2014](#)

[GRDC Fact Sheets: Irrigated wheat in the Murrumbidgee, Murray. Lifting yields from 5 t/ha to 8 t/ha or more](#)

<http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Can-high-performance-surface-irrigation-reduce-nitrogen-losses-in-broadacre-cropping-systems>

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/08/Sowing-date-heat-stress-and-frost-risk-in-irrigated-wheat-crops>

Rainfall between the 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 the best timing for strategic tillage in no-till systems.<sup>25</sup> Note that these results are from one season and research is ongoing, so any impacts are likely to vary with subsequent seasonal conditions (Figure 5).



Figure 5: Strategic tillage trials are under way at sites across eastern Australia. (Photo: Yash Dang)

### 1.6.2 Irrigation

Wheat responds well to irrigation. Critical periods for water are at tillering and flowering. Water requirements (in-crop) after starting with a full profile are ~3 ML/ha. The WUE for wheat ranges between 10 and 20 kg/mm soil water/ha. As an example, if the expected yield output is 15 kg/mm and the yield target is 4.5 t/ha, the water required would be ~300 mm or 3 ML irrigation water/ha (assuming no in-crop rainfall and a full moisture profile).

Consider near-infrared plant tissue testing in-crop to determine side-dressing rates of N to obtain optimum yield and protein levels.<sup>26</sup>

Growing irrigated wheat in southern New South Wales and northern Victoria is more than simply adding water to dryland varieties. Higher yields require increased monitoring and correct management practices to avoid yield penalties:

- Growing 8 t/ha of irrigated wheat requires more monitoring and management than 5 t/ha.
- Variety selection is integral to success for high grain-yield potential.
- Nitrogen supply at sowing should be 100–120 kg/ha, (this will include the amount already in the soil profile).

<sup>25</sup> Y Dang, V Rincon-Florez, C Ng, S Argent, M Bell, R Dalal, P Moody, P Schenk 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>

<sup>26</sup> DAFF Qld (2012) Wheat—planting information. Queensland Department of Agriculture Fisheries, and Forestry, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/planting-information>

## **i** More information

[GRDC Update Papers: Leading farmers have closed the yield gap](#)

[GRDC Update Papers: Managing resources and risk for 8 tonne cereal crops](#)

[DAF Qld: Wheat—planting information](#)

[DAF Qld: Managing water resources](#)

[GRDC Update Papers: Irrigation and automation—a look to the future](#)

## **i** More information

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW>

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Yield-Prophet-What-difference-can-it-make-to-crop-decision-making>

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Managing-data-on-the-modern-farm>

- To prevent lodging, avoid shoot numbers >800/m<sup>2</sup> at the first-node stage (Zadoks growth stage 31) through precise seed-rate calculation and placement. Use varieties with a lodging rating closer to 1 than 9.
- Maintain three green leaves per shoot at flowering through use of N topdressing, timely irrigations, and foliar fungicides for stripe rust and other diseases.
- Use a layout that allows irrigation and drainage in under 12 h.<sup>27</sup>

## 1.7 Yield and targets

Australia's climate, and in particular rainfall, is among the most variable on Earth; consequently, crop yields vary from season to season. In order to remain profitable, crop producers must manage their agronomy, crop inputs, marketing and finance to match each season's yield potential.<sup>28</sup>

Before planting, identify the target yield required to be profitable (Figure 6):

- Do a simple calculation to see how much water you need to achieve this yield.
- Know how much soil water you have (treat this water like money in the bank).
- Think about how much risk your farm can take.
- Consider how this crop fits into your cropping plan—will the longer term benefits to the system outweigh any short-term losses?
- Avoiding a failed crop saves money now and saves stored water for future crops.<sup>29</sup>



Figure 6: Before planting, identify the target yield. (Photo: Yash Dang)

Soil tests are available to assist in the assessment of paddock nutrient status.

<sup>27</sup> GRDC (2014) Lifting yields from 5t/ha to 8t/ha ... or more. Irrigated Wheat in the Murrumbidgee, Murray Fact Sheet, GRDC, 30 April 2014, <http://www.grdc.com.au/GRDC-FS-IrrigatedWheatNSWVic>

<sup>28</sup> T McClelland (2012) Yield- Prophet®—What difference can it make to crop decision making? GRDC Update Papers, 6 February 2012, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Yield-Prophet-What-difference-can-it-make-to-crop-decision-making>

<sup>29</sup> J Whish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Papers, 23 July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW>



Adequate phosphorus (P) is essential for the early growth of wheat (Table 3). Most Victorian soils are low in available P, and it is critical that some P and much of the crop requirement will need to be supplied through the application of fertilisers at sowing time. 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 wheat anticipated. The application may then be adjusted in the light of soil test results.

Table 3: Adequate soil phosphorous ranges for different soil types

Soil test reading (Colwell P)	Soil type
20–30 mg/kg	Sand
25–35 mg/kg	Loam
30–40 mg/kg	Clay

Nitrogen (N) availability is equally important. 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, use of long fallow and tillage methods. The availability of N in the soil is affected by many factors: soil organic matter, paddock history including fallowing, 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 should be done as close as possible to sowing time and at the same time each year.

Cropping advisors are a good source of support in determining fertiliser application strategies.<sup>30</sup>

### 1.7.1 Yield Prophet®

Scientists have aimed to support farmers' capacity to achieve yield potential by developing APSIM. APSIM is a farming systems model that simulates the effects of environmental variables and management decisions on crop yield, profits and ecological outcomes.

Yield Prophet® is an online crop-production model designed to present grain growers and consultants with real-time information about their crops. This tool provides growers with integrated production risk advice and monitoring of decision-support relevant to farm management.

Yield Prophet® delivers information from APSIM to farmers (and consultants) to aid their decision-making. Yield Prophet® has had some acceptance and adoption amongst innovative farmers and has made valuable impacts in terms of assisting farmers to manage climate variability at a paddock level.

Operated as a web interface for APSIM, Yield Prophet® generates crop simulations and reports. By matching crop inputs with potential yield in a given season, Yield Prophet® subscribers may avoid over- or under-investing in their crop. This is achieved primarily by conducting scenario analyses in which the effects of alternative management options on crop yield and potential profitability can be assessed and applied, and can thereby influence decision-making. The simulations provide a framework for farmers and advisers to:

- forecast yield
- manage climate and soil water risk
- make informed decisions about N and irrigation applications
- match inputs with the yield potential of their crop
- assess the effect of changed sowing dates or varieties
- assess the possible effects of climate change

<sup>30</sup> <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

## **i** More information

[GRDC Update Papers: Yield Prophet—what difference can it make to crop decision making?](#)

[Soil Quality Pty Ltd: Calculators—wheat yield potential calculator](#)

### How does it work?

Yield Prophet® generates crop simulations that combine the essential components of growing a crop including:

- a soil test sampled prior to planting
- a soil classification selected from the Yield Prophet® library of ~1000 soils, chosen as representative of the production area
- historical and active climate data taken from the nearest Bureau of Meteorology weather station
- paddock-specific rainfall data recorded by the user (optional)
- individual crop details

### 1.7.2 Seasonal outlook

Growers and advisers now have a readily available online tool. CropMate was developed by NSW Department of Primary Industries and can be used in pre-season planning to analyse average temperature, rainfall and evaporation. It provides seasonal forecasts and information about influences on climate, such as the impact of Southern Oscillation Index (SOI) on rainfall. The CropMate decision tool provides estimates of soil water and soil N, and frost and heat risk, as well as gross margin analyses of the various cropping options (Figure 7).

Download CropMate from the App Store on iTunes at: <https://itunes.apple.com/au/app/cropmate-varietychooser/id476014848?mt=8>



Figure 7: Screen shot of CropMate app. (Photo: NSW DPI)

For tips on understanding the drivers of weather and climate, including the SOI, visit the [Climate Kelpie](#) website. Case studies of farmers across Australia recruited as 'Climate Champions' as part of the Managing Climate Variability Climate Champion Program can also be accessed at the Climate Kelpie website.

[Australian CliMate](#) 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, and 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> or visit <http://www.australianclimate.net.au>

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 with all years. It explores the readily available weather data, 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:

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

For inputs, *Season's progress?* asks for the weather variable that is 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 a duration.

As outputs, text and two 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.<sup>31</sup>

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 or monthly outlooks and the forecasting of additional climate variables.<sup>32</sup>

### 1.7.3 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 water stored in the soil and rainfall during the growing season. It 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

Water-use efficiency can be considered at several levels:

- Fallow efficiency is the efficiency with which rainfall during a fallow period is stored for use by the following crop.
- Crop WUE is the efficiency with which an individual crop converts water transpired (or used) to grain.
- Systems WUE is the efficiency with which rainfall is converted to grain over multiple crop and fallow.

<sup>31</sup> Australian CliMate—Climate tools for decision makers, [www.australianclimate.net.au](http://www.australianclimate.net.au)

<sup>32</sup> J Sabburg, G Allen (2013) Seasonal climate outlook improvements changes from historical to real time data. GRDC Update Papers 18 July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Seasonal-climate-outlook-improvements-changes-from-historical-to-real-time-data>

## More information

[GRDC Update Papers: Practical production risk management—matching inputs with seasonal outlook](#)

[Climate Kelpie: Climate Champion Program](#)

[GRDC Update Papers: Seasonal climate outlook improvements—changes from historical to real-time data](#)

[Australian CliMate](#)

[GRDC: Managing frost risk—a guide for southern Australian grains](#)

## More information

[GRDC Update Papers: Dryland water-use efficiency—what is it and how to improve it](#)

[GRDC Update Papers: Opportunities with liquid systems](#)

[GRDC Fact Sheets: Water use efficiency. Converting rainfall to grain. Northern Region](#)

### Ways to increase yield

In environments where yield is limited by water availability, there are four ways of increasing yield:<sup>33</sup>

1. Increase the amount of water available to a crop (e.g. good summer weed control, stubble retention, long fallow, sowing early to increase rooting depth).
2. Increase the proportion of water that is transpired by crops rather than lost to evaporation or weeds (e.g. early sowing, early N, vigorous crops and varieties, narrow row spacing, high plant densities, stubble retention, good weed management).
3. Increase the efficiency with which crops exchange water for carbon dioxide to grow dry matter, i.e. transpiration efficiency (e.g. early sowing, good nutrition, varieties with high transpiration efficiency such as Spitfire<sup>(1)</sup>, Scout<sup>(1)</sup>, Drysdale<sup>(1)</sup>, Gregory<sup>(1)</sup>).
4. Increase the total proportion of dry matter that is grain, i.e. improve the harvest index (e.g. early-flowering varieties, delayed N, wider row spacing, low plant densities, minimising losses to disease, varieties with high harvest index such as H45<sup>(1)</sup>, Hindmarsh<sup>(1)</sup>, Wyalkatchem<sup>(1)</sup>, Espada<sup>(1)</sup>).

### More information

[GRDC Update Papers: How much water is lost from northern crop systems by soil evaporation](#)

### 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. Typical estimates of WUE and soil evaporation are listed in Table 4.

*We use a target WUE of 18 kg/ha/mm for wheat. From our benchmarking in 2014 of 149 wheat paddocks, 11% achieved this target, 46% achieved between 13 and 17 kg/ha/mm.*

*A practical WUE equation for farmers to use developed by James Hunt (CSIRO) is:*

*WUE = (yield x 1000) / available rainfall*

*Where avail rain = (25% Nov-Mar rain) + (GSR) – 60 mm evap*

### Agronomist's view

The French–Schultz model has been useful in giving growers 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.<sup>34</sup>

<sup>33</sup> JB Passioura, JF Angus (2010) Improving productivity of crops in water-limited environments. (Ed. DL Sparks) *Advances in Agronomy*, Vol. 106, pp. 37–75, Academic Press, <http://www.sciencedirect.com/science/article/pii/S0065211310060025>

<sup>34</sup> GRDC (2009) *Water use efficiency – converting rainfall to grain*. GRDC Fact Sheet Northern Region. *Water Use Efficiency Fact Sheet*, GRDC, [http://www.grdc.com.au/~media/607AD22DC6934BE79DEAA05DFBE00999.pdf](http://www.grdc.com.au/~/media/607AD22DC6934BE79DEAA05DFBE00999.pdf)

## **i** More information

<https://publications.csiro.au/rpr/download?pid=csiro:EP156113&dsid=DS2>

## **i** More information

GRDC Update Papers: [Farming systems design and water use efficiency—challenging the French–Schultz model](#)

Table 4: Typical parameters that could be used in the French–Schultz equation

Crop	Water-use efficiency (kg/ha.mm)	Soil evaporation (mm)
Wheat	18	100
Chickpea	12	100

In the wheatbelt of eastern Australia, rainfall shifts from winter-dominated in the south (South Australia, Victoria) to summer-dominated in the north (northern NSW and Queensland). The seasonality of rainfall, together with frost risk, drives the choice of cultivar and sowing date, resulting in a flowering time varying between October in the south and August in the north.

In eastern Australia, wheat crops are therefore exposed to contrasting climatic conditions during the critical period for grain formation, i.e. a window of ~20 days before and 10 days after flowering, which 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. They advise caution on the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single-crop and whole-farming-systems level, i.e. \$/ha.mm.<sup>35</sup>

### 1.7.4 Nitrogen-use efficiency

Soil type, rainfall intensity and the timing of fertiliser application largely determine N losses from dryland cropping soils.

Insufficient rainfall after surface application of N fertilisers can result in losses from the soil through volatilisation. The gas lost in this case is ammonia. Direct measurements of ammonia losses have found that they are generally <15% of the N applied, even less with in-crop situations. An exception occurred with the application of ammonium sulphate to soils with free lime at the surface, where losses were >25% of the N applied. Recovery of N applied in-crop requires sufficient in-crop rainfall for plant uptake from otherwise dry surface soil.<sup>36</sup>

A balance of nutrients is essential for profitable yields. Fertiliser is commonly needed to add the essential nutrients P and N. Lack of other essential plant nutrients may also limit production in some situations.

Knowledge of the nutrient demand of crops is essential in determining nutrient requirements. Soil testing and nutrient audits assist in matching nutrient supply to crop demand.

## 1.8 Disease status of the paddock

### 1.8.1 Soil testing for disease

PreDicta B (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:

- cereal cyst nematode

<sup>35</sup> D Rodriguez (2008) Farming systems design and water use efficiency (WUE). 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>

<sup>36</sup> G Schwenke, P Grace, M Bell (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>

- take-all (*Gaeumannomyces graminis* var. *tritici* and *G. graminis* var. *avenae*)
- Rhizoctonia bare patch (*Rhizoctonia solani* AG8)
- crown rot (*Fusarium pseudograminearum*)
- root-lesion nematode (*Pratylenchus neglectus* and *P. thornei*)
- stem nematode (*Ditylenchus dipsaci*)

Southern region grain producers can access PreDicta B via agronomists accredited by the South Australian Research and Development Institute (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.

The service is not intended for in-crop diagnosis, which is best achieved by sending samples of affected plants to your local plant pathology laboratory.

## More information

[SARDI: Predicta B](#)

### 1.8.2 Effects of cropping history

Continuous cereal cropping increases the risk of diseases including crown rot and tan spot. All winter cereals and many grassy weeds host crown rot, and it can survive for many years in infected plant residues. Infection can occur when plants come in close contact with those residues.<sup>37</sup>

Stubble burning is not recommended as a control for crown rot, and cultivation can increase the incidence of seed–stubble contact. Inter-row sowing is a recommended strategy.

High cereal intensity and inclusion of durum wheat in cropping programs are factors that increase levels of crown rot.<sup>38</sup>

Paddock history can also provide clues. Histories likely to result in high risk of crown rot include:

- durum wheat in the past 1–3 years
- winter cereal or a high grass burden from last season—crown rot fungus survives in winter cereal residues, dense stubble cover or where dry conditions have made residue decomposition slow
- break crops, which can influence crown rot in cereals by manipulating the amount of nitrogen (N) and moisture left in the soil profile
- paddocks that have high levels of N at sowing and/or low stored soil moisture at depth<sup>39</sup>
- wheat varieties grown in previous years<sup>40,41</sup>

## More information

[GRDC Fact Sheets: Grain protectants prevent pests](#)

<sup>37</sup> GRDC (2012) Crown rot—about the crown rot disease. GRDC Hot Topics, 10 July 2012, <http://www.grdc.com.au/Media-Centre/Hot-Topics/Crown-Rot>

<sup>38</sup> GRDC (2012) Crown rot—about the crown rot disease. GRDC Hot Topics, 10 July 2012, <http://www.grdc.com.au/Media-Centre/Hot-Topics/Crown-Rot>

<sup>39</sup> GRDC (2009) Understanding the disease underpins effective management. Southern and Western Region. Crown rot in cereals. GRDC Cereals Fact Sheet, GRDC, May 2009, <https://www.grdc.com.au/~media/AF642FA0A889465089D2B6C59E5CA22E.pdf>

<sup>40</sup> R Brill, S Simpfendorfer (2013) Resistance of eighteen wheat varieties to the root lesion nematode *Pratylenchus thornei*—Trangie 2011. In: NSW DPI Northern Grains Region Trial Results Autumn 2013, pp. 129–131, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf)

<sup>41</sup> R Brill, S Simpfendorfer (2013) Resistance of eighteen wheat varieties to the root lesion nematode *Pratylenchus thornei*—Trangie 2011. In: NSW DPI Northern Grains Region Trial Results Autumn 2013, pp. 129–131, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf)

## 1.9 Nematode status of the paddock

### 1.9.1 Nematode testing of soil

It is important to have paddocks diagnosed for plant parasitic nematodes so that optimal management strategies can be implemented. Testing your farm will tell you:

- if nematodes are present in your paddocks and at what density
- which species are present

It is important to know which species are present because some crop-management options are species-specific. If a particular species is present in high numbers, immediate decisions must be made to avoid losses in the next crop to be grown. With low numbers, it is important to take decisions to safeguard future crops. Learning that a paddock is free of these nematodes is valuable information because steps may be taken to avoid future contamination of that field.<sup>42</sup>

Testing of soil samples taken before a crop is sown provides valuable information.

### 1.9.2 Effects of cropping history on nematode status

Root-lesion nematode numbers build up steadily under susceptible crops and cause decreasing yields over several years. Yield losses >50% can occur in some wheat varieties, and up to 20% in some chickpea varieties. The amount of damage caused will depend on:

- the numbers of nematodes in the soil at sowing
- the tolerance of the variety of the crop being grown
- the environmental conditions

Generally, a population density of 2000/kg soil anywhere in the soil profile has the potential to reduce the grain yield of intolerant wheat varieties.

A tolerant crop yields well when high populations of root-lesion nematodes are present (the opposite is intolerance). A resistant crop does not allow root-lesion nematodes to reproduce and increase in number (the opposite is susceptibility).

The main tool for managing nematodes is growing resistant crops. In the case of crops such as wheat or chickpeas, choose the most tolerant variety available and rotate with resistant crops to keep nematode numbers at low levels. Information on the responses of crop varieties to root-lesion nematodes is regularly updated in grower planting guides. Note that crops and varieties have different levels of tolerance and resistance to *Pratylenchus thornei* and *P. neglectus* (see Table 5).<sup>43</sup>

Table 5: Susceptibility and resistance of various crops to root-lesion nematodes<sup>44</sup>

RLN species	Susceptible	Intermediate	Resistant
<i>Pratylenchus thornei</i>	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
<i>Pratylenchus neglectus</i>	Wheat, canola, chickpeas, mustard, sorghum (grain), sorghum (forage)	Barley, oats, canary seed, durum wheat, maize, navy beans	Linseed, field peas, faba beans, triticale, mungbeans, soybeans

<sup>42</sup> Queensland Primary Industries and Fisheries (2009) Root lesion nematodes—management of root-lesion nematodes in the northern grain region. Queensland Government, [http://www.daff.qld.gov.au/\\_data/assets/pdf\\_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf](http://www.daff.qld.gov.au/_data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf)

<sup>43</sup> K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root lesion nematodes. GRDC Update Papers, 16 July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes>

<sup>44</sup> 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 information

[Agriculture Victoria: Collecting soil and plant samples for nematode analysis](#)

For more information, download [GRDC Tips and Tactics—Root-lesion nematodes](#) and see [GrowNotes Wheat South Section 8. Nematodes](#).

## 1.10 Insect and pest status of paddock

### 1.10.1 Sampling of soil for insects

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 through lack of food.
- High levels of stubble on the soil surface can promote some soil insects because of the food source, but this can also mean that pests continue feeding on the stubble instead of the 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 numbers decline if stubble levels are very low.

### More information

[DAFWA: Identifying soil beetle pests](#)

Soil insect control measures are normally applied at sowing. Different insects require different control measures; therefore, 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.
2. 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.

### Germinating-seed bait technique

Immediately following planting rain:

1. Soak insecticide-free crop seed in water for at least 2 h to initiate germination.
2. Bury a dessertspoon of the seed under 1 cm of soil at each corner of a 5 m by 5 m square at five widely spaced sites per 100 ha.
3. Mark the position of the seed baits, because large populations of soil insects can destroy the baits.
4. One day after seedling emergence, dig up the plants and count the insects.

Trials have shown no difference in the type of seed used for 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.



## More information

[GRDC Update Papers: Surveillance and forecasts for mouse outbreaks in Australian cropping systems](#)

[GRDC Ground Cover: Mouse management a numbers game](#)

[GRDC Fact Sheets: Mouse control – Western Region](#)

[GRDC Hot Topics: Snail control before seeding](#)

[VNTFA: Slugs](#)

## Video

[Mouse management](#)

### **Detecting soil-dwelling insects**

Soil insects are often difficult to detect; 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 the websites of [Pest Genie Australia](#) or [APVMA](#).<sup>45</sup>

#### **1.10.2 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.<sup>46</sup>

<sup>45</sup> DAFF Qld (2011) How to recognise and monitor soil insects. Queensland Department of Agriculture, and Fisheries and Forestry, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects>

<sup>46</sup> 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

## 2.1 Varietal performance and ratings

For best results, use varieties yielding consistently well over several years that offer the best combination of yield potential, grain quality and disease resistance. Sow at least two different wheat varieties each year; this spreads the risk of frost and disease damage (Figure 1).

To ensure high yields, select varieties by considering:

- varieties that have performed well at a local level
- grain quality to attract premium payments
- good disease-resistance package
- maturity suited to sowing time
- strong seedling vigour
- resistance to lodging and shattering
- tolerance to herbicides
- tolerance to soil acidity or sodicity
- tolerance to pre-harvest sprouting
- ability to perform well in low or marginal moisture conditions
- good threshing ability
- tolerance to frost <sup>1</sup>

### More information

[GRDC National Variety Trials: Crop variety guides](#)

[Superior Seed Co.: Choosing new wheat varieties](#)

### Video

[NVT PLAYLIST - SA Trial Results 2014](#)



Figure 1: Sow at least two different wheat varieties each year; this spreads the risk of frost and disease damage. (Photo: Paul Jones Photography)

<sup>1</sup> P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide>

## **i** More information

[BCG/CSIRO/APSIM: Yield Prophet](#)

[BCG: Trial details. Agronomic information for growing biscuit wheats—2000](#)

[Southern Farming Systems: NVT wheat: should I diversify my wheat varieties?](#)

[Southern Farming Systems: Evaluation of early sown European wheat varieties without grazing—Nile, Tas.](#)

[Southern Farming Systems: Wheat variety trial—Bairnsdale, Vic.](#)

[Southern Farming Systems: Cereal Cropping in Gippsland—evaluating suitable wheat & barley varieties](#)

[MFGM: MacKillop Farm Management Group trials 2015](#)

[BCG: Research & Extension](#)

## 2.1.1 Yielding ability and GRDC-funded National Variety Trials

Productivity of the grains industry depends on the continued adoption and deployment of new technologies, including the adoption of new varieties with superior yield and useful disease-resistance characteristics. When considering a new variety, growers should compare the yield, grain quality and disease resistances of the new variety with the currently grown varieties.

National Variety Trials (NVT) collect the most relevant varieties for each region, both new and old, and test them alongside the elite lines from the breeding programs. For all information on the released varieties in the NVT, visit the website ([www.nvtonline.com.au](http://www.nvtonline.com.au)).<sup>2</sup>

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 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 will provide the most accurate prediction of relative yield performance of varieties for an environment.<sup>3</sup>

For more information about the online crop production model Yield Prophet®, see [GrowNotes Wheat South Section 1. Planning and paddock preparation](#).

### [Alkaline Soils Group](#)

Established in 1999 by farmers and consultants, the [YP Alkaline Soils Group](#) aims to identify research and to demonstrate and promote best practice farming systems in medium-rainfall areas with alkaline soils. The group is run by a voluntary committee of farmers and agronomists and has two part-time staff. Research and communication activities are subcontracted to specialists.

### [Farmlink Research](#)

[FarmLink](#) is made up of individual growers, grower groups, research organisations, advisers and agribusiness in southern New South Wales (NSW). FarmLink gives growers the power to influence research priorities and to be actively involved in the research process. The main objective of FarmLink is the co-ordination and communication of research and development activities funded privately, publically and by growers' groups within the region.

### [Grain Orana Alliance](#)

[Grain Orana Alliance](#) aims to facilitate greater cooperation and develop linkages between research providers, growers and consultants across the region who currently compete for funds and, most importantly, lack the capacity to validate research results on-farm in a timely manner and extend research outcomes outside their respective boundaries cost-effectively.

### [Hart Field Site](#)

The [Hart Field Site](#) is a premier agronomic field demonstration and trial site in South Australia.

### [Liebe Group](#)

The [Liebe Group](#) is a progressive group working together to sustain and enhance the rural environment through a whole-systems approach to agriculture.

### [Mallee Sustainable Farming Project](#)

[Mallee Sustainable Farming Inc.](#) is a farmer-guided participatory research, development and extension organisation. Their mission is to increase the adoption of sustainable and profitable farming systems in the low-rainfall Mallee regions of NSW, Victoria and South Australia.

<sup>2</sup> National Variety Trials (2014) Queensland 2014 wheat varieties. GRDC/Department of Agriculture, Fisheries and Forestry Queensland, <http://www.grdc.com.au/NVT-QLD-WheatVarietyGuide>

<sup>3</sup> A Kelly, A Smith, B Cullis (2013) Which variety should I grow? New statistical methods for NVT allow for better decision making. 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>

## More information

<http://www.sfs.org.au/announcements/wheat-varieties-yield-is-king>

[http://dpiwve.tas.gov.au/documents/species-for-profit-book\\_web.pdf](http://dpiwve.tas.gov.au/documents/species-for-profit-book_web.pdf)

<http://www.extensionaus.com.au/cereal-disease-guides/>

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Understanding-farmer-decision-making-and-adoption-behaviour>

### FAQ

## 2.2 Variety characteristics

A survey of Victorian wheat growers shows that the most valuable traits of wheat are strongly related to end use or classification, yield, and suitability to the sowing window.<sup>4</sup>

Wheat variety characteristics are presented below, including flour milling assessment (Table 1), agronomic traits (Table 2), and yield and disease resistance (Table 3) to aid decision-making.

Table 1: Victorian wheat varieties: a domestic flour miller's assessment<sup>5</sup>

Hard wheat	End product category				
	Variety	Preferred grade	Max class grade	Plant bakery	Artisan bread
Axe	AH	AH	1	1	Very poor water absorption, strong dough characteristics and long mix time.
Bolac	AH	AH	2	2	Marginal AH - strong dough characteristics.
Chara	AH	AH	1	2	Optimum value as separate segregation due to excess mix requirement.
Condo	AH	AH	1	2	Marginal strong dough & mix time. Possible specialist application.
Corack	APW	APW	2	1	Acceptable APW quality. Suit domestic mills.
Correll	AH	AH	3	1	Acceptable AH quality.
Cosmick	AH	AH	3	2	Acceptable AH for Domestic market.
Derrimut	AH	AH	3	1	Appears acceptable as AH quality to suit plant bakery.
EGA Gregory	APW*	APW*	2	1	Limited data, but indicate suitable for domestic APW.
EGA Wedgetail	APW*	APW*	1	2	Over strong APW. Long mix requirement. Appears to suit specialist segregation.

<sup>4</sup> S Longley, E Seymour, G Kaine (2012) Farmer identification of valuable traits in agricultural crops and pastures: case studies in adoption and decision-making. Department of Primary Industries Victoria, <http://geoffkaineresearch.com/download/getfile/22>

<sup>5</sup> National Variety Trials (2015) NVT Victorian winter crop summary 2015. GRDC/Department of Economic Development, Jobs, Transport and Resources Victoria, <http://www.grdc.com.au/Resources/Publications/2015/03/NVT-Victorian-Winter-Crop-Summary-2015>

Hard wheat		End product category			
Variety	Preferred grade	Max class grade	Plant bakery	Artisan bread	Comment
Elmore CL Plus	AH	AH	3	1	Good water absorption & acceptable bake performance. Acceptable AH quality.
Emu rock	AH	AH	3	2	Acceptable AH. Marginal long mix requirement.
Estoc	APW	APW	2	1	Marginal APW quality. Some interest from domestic mills.
Forrest	APW	APW	2	1	Acceptable APW quality for Domestic market.
Gladius	AH	AH	1	2	Very strong dough properties with excessive mix time.
Grenade CL Plus	AH	AH	2	2	Marginal strong. Limited domestic interest.
Justica CL Plus	APW	APW	1	3	Strong dough. Appears to suit specialist segregation.
Kellalac	APW	APW	2		Acceptable APW quality - has weak dough & poor bake.
Kiora	AH	AH	2	2	Marginally strong dough. Some interest from Domestic market.
Kord CL Plus	AH	AH	3	1	Appears suitable for domestic mills.
Livingston	AH	AH	3	2	Acceptable as AH quality to suit plant bakery.
LRPB Cobra	AH	AH	3	1	Appears acceptable. Some concerns over low viscosity and high yellow pigment.
LRPB Dart	AH	AH	2	1	Good dough & bakery performance, but low FN. Limited interest.
LRPB Gauntlet	APW	APW	3	1	Appears acceptable. Good dough & bakery results.
LRPB Lancer	APW*	APW*	2	1	Acceptable APW. Good water absorption & bake volume, but marginal long mix time.
LRPB Lincoln	AH	AH	2	1	Appears to have limited suitability as domestic AH.
LRPB Merlin	AH	AH	2	2	Strong dough, long mix. Possibly specialist applications.
LRPB Phantom	AH	AH	3	1	Appears to suit domestic mills.
LRPB Scout	AH	AH	2	1	Suitable AH, marginal long mix time.
LRPB Spitfire	AH	AH	2	2	Long mix requirement and short extension, appears limited suitability for domestic mills.
LRPB Trojan	APW	APW	2	1	Some interest from domestic mills. Marginal water absorption, long mix time but good bake volume.
LRPB Viking				2	Limited data available. Early indication is that it has excessive strength & mix time.
Mace	AH	AH	3	1	Suitable as domestic AH.
Magenta	APW	APW	2	1	Marginally acceptable for plant bakeries.
Merinda	AH	AH	3	3	Has strong and extensible dough properties.
Sentinel 3R	ASW	ASW	1	1	Appears to have limited suitability for domestic mills.
Shield	AH	AH	3	1	Marginal strong. Expect some domestic interest.
Suntop	AH	AH	2	2	Strong AH. Good water absorption, but marginally long mix time.
Wallup	AH	AH	1	2	Long mix requirement. Appears to suit specialist segregation. Limited interest from domestic millers.
Yitpi	AH	AH	3	2	Acceptable AH quality.
Young	AH	AH	2	2	Acceptable AH quality - has strong dough & long mix time.

Hard wheat		End product category				
Soft or noodle wheat						
Variety	Preferred grade	Max class grade	Biscuit	Cake	Hot plate goods	Comment
Barham	Soft	SF1	3	3	2	Acceptable Biscuit quality
LRPB Gazelle	Soft	SF1	3	2	1	Acceptable Biscuit quality
LRPB Impala	Soft	SF1	3	2	1	Acceptable Biscuit quality
Yenda	Soft	SF1	3	2	1	Acceptable Biscuit quality

Interpretation provided by David Hogan, Quality Operations Manager, Laucke Flour Mills. On the quality scale: 3, preferred for a particular varietal end use; 2, suitable; 1, not suitable

Table 2: *Wheat variety agronomic guide*<sup>6</sup>

Screening, lodging and sprouting resistance: R, resistant; S, susceptible; M, moderately; V, very. Maturity: E, early; M, mid; L, late; (+W), winter wheat. Height: S, short; M, medium; T, tall. Coleoptile length: S, short; M, medium; L, long. Head colour and type: W, white; B, black; R, red; A, awned; AL, awnless. Soil tolerance: I, intolerant; T, tolerant; M, moderately

Bread wheat	Maximum quality Vic	Rainfall			Screenings	Maturity	Height	Coleoptile length	Lodging	Sprouting	Head type		Soil tolerance	
		Low <400mm	Med 400-500mm	High >500mm							Colour	Awn	Boron	Acid
Axe	AH	✓			MR	E	M-S	MS	MR	SVS	W	A	I	I
Bolac	AH		✓	✓	S	M-L	M	M	MR	S	W	A	I	I
Chara	AH	✓	✓	✓	MR	M-L	M	MS	MR	S	W	A	MI	MI
Condo	AH	✓	✓		R	E	MT	M	MS	S	W	A	I	MT
Corack	APW	✓	✓		R	E-M	S	MS	MR	S	W	A	I	T
Correll	AH	✓	✓		MR	M	M	ML	MS	SVS	W	A	MT	MT
Cosmick	AH	✓	✓		MRMS	E-M	M	L	MRMS		W	A		
Derrimut	AH	✓	✓		MS	E-M	MS	MS	MRMS	S	W	A	MT	
EGA Gregory	APW*		✓	✓		M-L	MT		MS	S	W	A		MT
EGA Wedgetail	APW*			✓	MR	ML (+W)	M	MS	MR	S	W	A	I	MT
Elmore CL Plus	AH		✓		MS	M	M	M	MRMS	S	W	A	I	I
Emu Rock	AH	✓	✓		R	E	S	M	R	S	W	A		
Estoc	APW	✓	✓			M-L	M	ML	MR	MRMS	W	A	MT	MT
Forrest	APW		✓	✓	MR	L	M	S-M		S	W	A		
Gladius	AH	✓	✓		MR	M	M	M	MRMS	SVS	W	A	MT	MT
Grenade CL Plus	AH		✓		MR	EM	MT	ML		S	W	A	MT	MT
Justica CL Plus	APW		✓		MR	M	M	M	R	S	W	A	MT	MT
Kellalac	APW		✓	✓	MR	L	M	M		S	W	A	MI	I
Kiora	AH		✓	✓	MS	M-L	M	M	MR	S	W	A	MI	MI
Kord CL Plus	AH	✓	✓			M	M			SVS	W	A	MT	MT
Livingston	AH	✓	✓		MRMS	E-M	M		MS	S	W	A	I	I
LRPB Cobra	AH	✓	✓	✓	MRMS	E-M	S		MR	SVS	W	A	I	MT
LRPB Dart	AH	✓	✓		MRMS	E	SM	L		S	W	A	I	MT
LRPB Gauntlet	APW		✓	✓	MRMS	M-L	SM	M		S	W	A	I	MT
LRPB Lancer	APW*		✓	✓	MR	M-L	S	M	MR	S	W	A	I	MI-I
LRPB Lincoln	AH	✓	✓	✓	MR	M	M	MS	MS	SVS	W	A	I	MT

<sup>6</sup> National Variety Trials (2015) NVT Victorian winter crop summary 2015. GRDC/Department of Economic Development, Jobs, Transport and Resources Victoria, <http://www.grdc.com.au/Resources/Publications/2015/03/NVT-Victorian-Winter-Crop-Summary-2015>

Bread wheat	Maximum quality Vic	Rainfall			Screenings	Maturity	Height	Coleop length	Lodging	Sprouting	Head type		Soil tolerance	
		Low <400mm	Med 400-500mm	High >500mm							Colour	awn	Boron	Acid
LRPB Merlin	AH		✓		MR	E-M	M			MS	W	A	I	
LRPB Phantom	AH		✓	✓	MR	M-L	MT			S	W	A	MT	MT
LRPB Scout	AH	✓	✓	✓	MR	M	M	ML	MRMS	MS	W	A	MI	MT
LRPB Spitfire	AH	✓	✓		MR	E-M	M	L	MS	S	W	A	I	MT
LRPB Trojan	APW		✓	✓	MR	ML	M	M	MR	MSS	W	A	MT	MT-MI
LRPB Viking			✓	✓		ML	MT	MS	MS	S	W	A	I	MT-MI
Mace	AH	✓	✓		MR	E	M	MS	MR	S	W	A	MT	MT
Magenta	APW	✓	✓		MS	M-L	M	L	MRMS	S	W	A	I	MT
Merinda	AH	✓	✓			M	M		MRMS		W	A		
Sentinel 3R	ASW		✓	✓	MRMS	ML	M	S	MRMS	S	W	A		MT
Shield	AH	✓	✓		MR	EM	SM	S		S	W	A	I	MT
Suntop	AH	✓	✓	✓	MRMS	M	M	M	MR	SVS	W	A	I	MT
Wallup	AH		✓		MR	M	M	M	MR	S	W	A	I	I
Yitpi	AH	✓	✓		MR	M	MT	ML	MS	MS	W	A	MT	MT
Young	AH	✓	✓		MS	E-M	M	M	MSS	S	W	A	I	MT
<b>Biscuit wheat</b>														
Barham	ASF1		✓	✓	MR	M	M	ML	MS	S	W	AL	I	I
LRPB Gazelle	ASF1		✓	✓	MRMS	M-L	M		MR	S	W	A	I	MT
LRPB Impala	ASF1	✓	✓	✓	MR	E-M	ML		MS	MSS	W	A	I	MT
Yenda	ASF1		✓	✓	MR	M-L	SM	S	RMR	S	W	A	MT	MT
<b>Durum</b>														
Caparoi	ADR		✓			M	S-M	S-M	MR	M				I
DBA Aurora	ADR		✓		R	M	M		MR	MR	W	A		
EGA Bellaroi	ADR		✓		R	M	S-M	S	R	M	W	A	I	I
Hyperno	ADR		✓			M	M		MR	MR	W	A	I	
Jandaroi	ADR	✓	✓			E	M	S-M	MR	MR				I
Saintly	ADR	✓	✓			E				S	W	A	I	
Tjilkuri	ADR				MS	M	M			S	W/B	A	T	
WID802	ADR				MS	E-M				MR				
Yawa	ADR				MS	E-M				MR				
<b>Feed wheat</b>														
Beaufort	Feed		✓	✓		ML	M		MR-MS	MR	R	AL		MT
Manning	Feed			✓		L (+W)					W	AL		
Naparoo	Feed			✓		L (+W)					W	A		
Preston	Feed			✓		L	S		MR			A		
SF Adagio	Feed		✓	✓		M-L (+W)					R	A		
SF Scenario	Feed			✓		L (+W)					R	AL		
SQP Revenue	Feed			✓		L (+W)	S				R	AL		

Table 3: Mean yield (as % of district average) of varieties from SARDI and NVT trials (2009–13), and reaction to common diseases and to black point, which is a physiological response to certain humid conditions <sup>7</sup>

No. of trials for each variety in each district is in italics; –, insufficient data. Reaction: R, resistant; S, susceptible; M, moderately; V, very; –, variety to be evaluated (stripe rust ratings are for new WA Yr17 strain). Information on disease reaction was provided by the Field Crop Pathology Unit (SARDI) and compiled before the full data for 2014 were available. Contact Dr Hugh Wallwork (08 8303 9382)

	Agricultural district												Stem Rust	Stripe Rust#	Leaf Rust	Septoria tritici blotch	Yellow leaf spot	Powdery Mildew	Black point
	Lower Eyre Pen		Upper Eyre Pen		Murray Mallee		Mid North		Yorke Pen.		Upper South East								
AGT Katana	102	15	104	31	105	28	103	21	103	16	103	17	MSS	MRMS	MS	MS	MS	MRMS	S
Axe	97	15	99	31	99	28	99	21	97	16	98	17	MS	RMR	MR	SVS	S	MSS	S
Barham											93	17	MR	MSS	MRMS	MSS	MSS	SVS	MRMS
Bolac											96	6	MRMS	RMR	MS	MS	S	MRMS	MSS
Catalina	96	14	97	31	96	28	96	21	95	16	96	17	MR	MS	R	MS	MSS	MSS	S
Cobra	107	9	104	18	104	12	108	8	109	6	109	8	RMR	MSS	MR	MSS	MRMS	MSS	MSS
Corack	110	12	110	25	111	24	112	17	110	13	110	14	MR	MS	S	MSS	MR	VS	MSS
Correll	100	15	101	31	102	28	99	21	99	16	98	17	MRMS	MRMS	MSS	MRMS	SVS	MRMS	MS
Cosmick	-	-	-	-	-	-	-	-	-	-	-	-	MRMS	MSS	S	S	MR	MS	
Dart	99	8	99	12	99	12	101	13	99	10	100	8	MR	MRMS	RMR	S	MSS	MRMS	MRMS
Emu Rock	104	12	107	25	108	24	106	17	104	13	104	14	MRMS	MRMS	MSS	S	MRMS	MSS	MS
Espada	102	15	106	31	107	28	102	21	102	16	101	17	MR	MRMS	R	S	MS	S	S
Estoc	102	15	103	31	103	28	101	21	102	16	101	17	MR	MRMS	MRMS	S	MSS	MSS	MS
Gladius	100	15	102	31	102	28	101	21	100	16	100	17	MR	MRMS	MS	MSS	MS	S	MS
Grenade CL Plus	96	9	99	18	99	18	95	12	96	9	94	11	MR	MRMS	MS	MSS	S	MSS	MS
Harper	102	5	103	7	104	12	100	9	101	7	99	7	MRMS	MS	MRMS	MSS	MSS		RMR
Impala											100	17	RMR	MR	S	SVS	MSS	RMR	MRMS
Justica CL Plus	98	12	99	25	99	24	98	17	98	13	98	14	MR	MRMS	MSS	SVS	S	S	S
Kiora											-	-	RMR	RMR	MR	MS	MSS	MS	MRMS
Kord CL Plus	98	9	102	19	102	18	98	13	98	10	97	10	MR	MRMS	MS	MSS	MSS	MSS	MR
Mace	107	15	110	31	110	28	107	21	107	16	105	17	MR	SVS	MS	MRMS	MRMS	MSS	MS
Magenta	102	12	104	25	104	22	100	21	102	16	100	13	RMR	MS	MRMS	MRMS	MRMS	MRMS	S
Mackellar											-	-	MR	RMR	VS	MRMS	MRMS	MRMS	S
Orion											93	17	MR	MSS	R	MS	MSS	MS	SVS
Peake	100	12	99	25	98	27	101	21	99	10	100	17	MR	MRMS	R	MS	S	MRMS	MSS
Phantom	103	12	99	25	99	24	102	17	102	13	102	14	MRMS	MR	MS	MRMS	SVS	MRMS	MR
Scout	108	15	104	31	105	28	110	21	108	16	109	17	MR	MS	R	MS	SVS	MRMS	S
Sentinel											97	9	RMR	RMR	R	MRMS	MS	R	MSS
Shield	101	9	103	18	104	18	102	12	100	9	100	7	RMR	MR	R	MSS	MSS	MR	MS
SQRevenue											82	4	RMR	R	S	MS	MS	R	MSS
Trojan	110	9	108	18	109	18	109	12	111	9	110	11	MR	MR	MRMS	MS	MSS	-	MRMS
Wallup	103	10	100	12	100	11	104	17	104	13	105	14	RMR	MRMS	S	S	MSS	S	MR
Wyalkatchem	106	15	105	31	105	28	106	21	106	16	106	17	MS	S	MSS	MR	MR	SVS	MS
Yitpi	99	11	99	25	99	22	96	17	98	13	97	13	S	MRMS	MSS	MS	SVS	MRMS	MS
<b>av trial yield t/ha</b>	<b>4.49</b>	<b>2.38</b>	<b>2.42</b>	<b>3.77</b>	<b>4.51</b>	<b>4.48</b>													

<sup>7</sup> SAGIT (2015) South Australian sowing guide 2015. GRDC/SARDI, <http://grdc.com.au/SASowingGuide2015>



	Agricultural district						Stem Rust	Stripe Rust#	Leaf Rust	Septoria tritici blotch	Yellow leaf spot	Powdery Mildew	Black point	
	Lower Eyre Pen	Upper Eyre Pen	Murray Mallee	Mid North	Yorke Pen.	Upper South East								
<b>Durums</b>														
DBA-Auroa				111	9	109	9	RMR	RMR	RMR	-	MRMS	MR	MS
Caparoi				98	15	101	15	MR	MR	MRMS	RMR	MR	-	MSS
Hyperno				107	15	103	15	R	MR	RMR	RMR	MRMS	MR	MS
Saintly				104	15	105	15	MR	MR	MRMS	MRMS	MRMS	VS	MS
Tamaroi				97	15	99	15	MR	MR	MR	S	MRMS	MSS	MS
Tjilkuri				104	15	104	15	MR	MR	MR	MRMS	MRMS	S	MSS
WID802				110		107		RMR	MR	RMR	MR	MRMS	MRMS	MSS
Yawa				115	15	110	15	RMR	MR	MR	MR	MRMS	MS	MRMS
<b>av variety yield t/ha</b>				<b>3.74</b>		<b>3.97</b>								

**i More information**

[Southern Farming Systems: Wheat varieties—yield is king](#)

[DPIWE: Species for profit—a guide for Tasmanian pastures and field crops](#)

[extensionAUS: Cereal disease guides](#)

[GRDC Update Papers: Understanding farmer decision making and adoption behaviour](#)

[GRDC: NVT Victorian winter crop summary 2015](#)

[GRDC: South Australian sowing guide 2015](#)

**2.2.1 Maturity**

The maturity, or length of time taken for a variety to reach flowering, depends on vernalisation, photoperiod and thermal time requirements. Recommended sowing times are arrived at by assessing the maturity of varieties in different environments and with different sowing times. Figure 2 shows the variation in development stages when a variety is sown on different dates. <sup>8</sup> Some varieties have a wide planting window and they are not adversely affected by a later sowing date, for example EGA Gregory<sup>1, 9</sup>

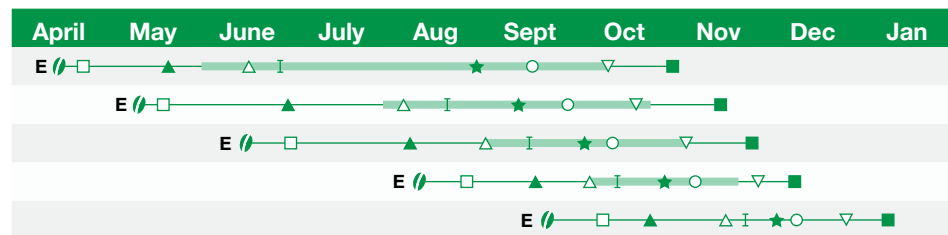


Figure 2: Development stages for varieties sown on different dates. (Based on M Stapper and R Fischer 1990)

The solid line in each panel is the estimated grain yield. The dashed lines are upper and lower 95% confidence limits.

It is critical to match variety and sowing date so that flowering occurs early enough to allow a long grain-filling period before the high evaporative demands and soil-water deficit of early summer. The flowering period must also be late enough to avoid damage by frosts in early spring.

No-till farming and stored summer moisture means many growers now ‘calendar sow’, i.e. start sowing at the earliest opportunity within a variety’s recommended sowing window, regardless of the autumn break.

Understanding how each variety responds to the environment will help to target varieties to their best sowing time. <sup>10</sup>

Varieties generally flower in the same order across years and sowing times.

Varieties generally flower in the same order across years and sowing times.

<sup>8</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

<sup>9</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

<sup>10</sup> P Martin, H Eagles, K Cane (2014) Flowering time of wheat varieties in New South Wales. GRDC Update Papers, 4 March 2014, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Flowering-time-of-wheat-varieties-in-New-South-Wales>

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Managing-the-risks-of-early-sown-wheat-in-South-West-Victoria>

<http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Early-sowing-in-Victoria-2014>

## More information

[GRDC Factsheets: Time of sowing](#)

[Research paper: Grain protein concentration of several commercial wheat varieties](#)

Varieties generally flower in the same order across years and sowing times.

For more information, see <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/What-is-driving-flowering-time-differences-of-wheat-varieties-between-years><sup>11</sup> For more information, see the GRDC project summary '[What is driving flowering time differences of wheat varieties between years](#)'.<sup>12</sup>

<http://www.grdc.com.au/Resources/Factsheets/2011/03/Time-Of-Sowing>

For more information on the influence of sowing time, see [GrowNotes Wheat South Section 3. Planting](#).

### 2.2.2 Varieties

Information about each variety is presented as overview statements, then as comparison tables of yield, crop growth and disease-reaction characteristics.

Abbreviations used:

- $\text{\textcircled{D}}$  denotes that Plant Breeder Rights apply
- S, MS, VS: susceptible, moderately susceptible, very susceptible
- R, MR: resistant, moderately resistant
- (p), provisional rating
- AGT, Australian Grain Technologies
- CCN, cereal cyst nematode
- BYDV, Barley yellow dwarf virus
- RLN, root-lesion nematode
- APR, adult plant resistance
- APH, Australian Prime Hard (min. protein 13%)
- AH, Australian Hard (min. protein 11.5%)
- APW, Australian Premium White (min. protein 10%)
- ASW, Australian Standard White
- ADR, Australian Premium Durum
- ASWN, Australian Standard Noodle (protein 9.2–11%)
- APNW, Australian Premium Noodle (protein 10–11.5%)
- ASFT, Australian Soft (protein 9.5%)
- FEED, Australian Feed
- \* denotes default classification
- EPR, end point royalty, 2015–16 quoted as \$/t ex-GST

#### *Bread wheats*

AGT Katana $\text{\textcircled{D}}$ : an early flowering, premium quality variety. Derived from Kukri, Katana has good physical grain quality, similar to Yitpi, and yields similar to Wyalkatchem on average. MR to rust, MS to CCN, MS to yellow leaf spot, MR–MS to powdery mildew. Seed available from AGT (conditional Seed Sharing<sup>TM</sup> allowed).

<sup>11</sup> GRDC (2014), What is driving flowering time differences of wheat varieties between years. <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/What-is-driving-flowering-time-differences-of-wheat-varieties-between-years>

<sup>12</sup> P Martin, M Gardner, G McMullen (2014) What is driving flowering time differences of wheat varieties between years. GRDC Update Papers, 5 March 2014, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/What-is-driving-flowering-time-differences-of-wheat-varieties-between-years>

**Axel**: APW classification in NSW. Very early maturity, similar to or slightly earlier than H45. MR–MS to stem rust, R–MR to stripe rust, MR to leaf rust, S to yellow leaf spot and CCN. Axel is not boron-tolerant. S–MS to black point. Produces very large grain with low screenings. (AGT)

**Bolac**: APH quality in southern NSW, APW in central and northern NSW. Later maturing than Chara. Adapted to mildly acidic, neutral and alkaline soils. MR–MS to stem rust, R–MR to stripe rust and black point, MS to leaf rust, S to yellow leaf spot. Small grain size. (Viterra)

**Chara**: AH quality in southern zone. White-grained and suited to medium–high-rainfall zones. MR–MS to stem rust, MS–S to stripe rust, S(p) to leaf rust, R to CCN, MS–S to yellow leaf spot. Performs well on the moderately acid soils of central and north-eastern Victoria and southern NSW and irrigation where high yields are possible. Good straw strength. Has a reputation for waterlogging tolerance. Registered 1999 and marketed by Seednet. EPR \$1.

**Condo**: AH quality in southern zone. A very early-maturing variety. Excellent yield potential in north-central and north-eastern Victoria and southern NSW. R–MR to stem rust, MS–S to stripe rust, MR–MS(p) to leaf rust, MR to CCN, MS–S to yellow leaf spot. Moderately tolerant to aluminium, large grain size, low screenings and intermediate for sprouting tolerance. Released 2014, tested as VX1634. Marketed by AGT. EPR \$3.25.

**Corack**: an early-maturing Wyalkatchem derivative that has yielded well in low- and medium-rainfall environments and/or with sharp finishes to the growing season. It has high straw strength, and is rated R to CCN and yellow leaf spot. May be suitable for a wheat-on-wheat situation, low-rainfall environments or late sowings. Rated MR to stem rust and MS to stripe and leaf rust, S to powdery mildew and black point. Has a high level of tolerance to acid soils. Has an APW classification for southern NSW. (AGT)

**Correll**: AH quality (southern zone). Fully awned with midseason maturity. MR–MS to stem and stripe rust, S(p) to leaf rust, MR to CCN, S–VS yellow leaf spot. Tolerant of boron toxicity, S–VS to pre-harvest sprouting and low test weights. Released 2007 and marketed by AGT. EPR \$2. Generally higher in grain yield than Yitpi, but averages ~3 kg/hL lower test weight and is susceptible to sprouting. 2–5 days earlier flowering than Yitpi and considerably more when sown very early. Seed available from AGT (conditional Seed Sharing™ allowed).

**Cosmick**: AH quality (southern zone). Fully awned with early to midseason maturity. MS to stem rust MS–S to stripe rust, S(p) to leaf rust, MS to CCN, MR–MS to yellow leaf spot. Good wheat-on-wheat option where CCN is managed. Excellent yield, moderate grain size, similar to Yitpi and good test weight. Released 2014, tested as IGW3423 and marketed by Intergrain. EPR \$3.85. Notes for South Australia: Cosmick has had limited evaluation in SA NVT (2013 only). Seed from Intergrain affiliates in 2015.

**Derrimut**: AH quality (southern zone). Semi-dwarf with early to midseason variety, widely adapted in Victoria. MR to stem rust, MS–S to stripe rust, MS(p) to leaf rust, R to CCN, S to yellow leaf spot. Moderately tolerant of boron toxicity and moderate grain size. Released 2007 and marketed by Nuseed. EPR \$2.95.

**EGA Gregory**: APH quality in northern NSW, AH quality in central and southern NSW. Similar maturity, straw strength and height to Batavia and Strzelecki. MR to leaf, stem and stripe rust. Good tolerance to RLN (*P. thornei*). S–MS to yellow leaf spot, S to crown rot, MR–MS to common root rot. (Pacific Seeds)

**EGA Wedgetail**: APW\* quality (southern zone). A mid- to long-season, dual-purpose winter wheat. Developed for early sowing, suited to medium–high-rainfall areas. Has a similar maturity to Rosella. MR–MS to stem rust, MS to stripe rust and leaf rust, S to CCN, MS–S to yellow leaf spot. Tolerant of acid soils and suitable for early winter grazing. Registered 2002 and marketed by Seednet. EPR \$1.45.

**Elmore CL PLUS**: AH quality classification in NSW. A mid-maturing variety with Clearfield® Plus technology, which provides tolerance to label rates of Intervix® herbicide. Has an adaptation pattern similar to Janz and is expected to perform well in

areas of moderate to high yield potential in NSW, providing an alternative strategy for in-crop weed control. Rated as MR–MS to stripe rust, R–MR to leaf rust, MR to stem rust, S to yellow leaf spot and CCN. (AGT)

**Emu Rock**<sup>Ⓛ</sup>: AH classification for southern NSW. Early-season variety with broad adaptation. Produces large grain with good test weight and has a low susceptibility to screenings. MS to yellow leaf spot, MR–MS to stripe and stem rust, MS–S to leaf rust, S to CCN. Bred by InterGrain, marketed by Nuseed. This early-maturing, large-grained wheat is derived from Kukri. Notes for South Australia: MR–MS to yellow spot. Across two seasons of NVT in SA, Emu Rock has shown yields aligning with Wyalkatchem. Seed is available from Intergrain (conditional Seed Sharing™ allowed).

**Espada**<sup>Ⓛ</sup>: sister line to Gladius, with higher yield potential. Agronomically similar to Gladius and MS to CCN, but features improved leaf rust resistance. Espada has APW quality and is susceptible to sprouting like Gladius. Seed available from AGT (conditional Seed Sharing™ allowed).

**Estoc**<sup>Ⓛ</sup>: ASW quality in southern NSW. Mid–late season variety, 1–3 days earlier than Yitpi. MR to stem rust, MR–MS to stripe (including Yr) and leaf rust, R–MR to CCN, S–VS to RLN (*P. thornei*) and boron tolerance. It is a mid–late-maturing variety like Yitpi, with better yellow leaf spot (MS–S) resistance and significantly higher grain yields. Eligible for APW classification, with good physical grain quality like Yitpi. It has shown good sprouting tolerance. Seed available from AGT (conditional Seed Sharing™ allowed).

**Forrest**: APW quality (southern zone). Awned semi-dwarf, long-season variety suited to the high-rainfall zones for early April–early May sowing. R–MR to stem and stripe rust, MS–S(p) to leaf rust, S to CCN, MR–MS to yellow leaf spot. Possesses resistance/tolerance to *Wheat streak mosaic virus*. Released 2011. Bred by Advantage Wheats and marketed by Seednet. EPR \$3.50.

**Gladius**<sup>Ⓛ</sup>: AH quality in southern NSW, APW in central and northern NSW. Mid–quick-season maturity, similar to Diamondbird and Drysdale. Maintains high relative grain yields under drought stress. MR–MS to stripe rust, MR to stem rust, MS to leaf rust and yellow leaf spot, S to *Septoria tritici* blotch. Tolerant to boron. MS to CCN, S to RLN (*P. neglectus*). Gladius has midseason maturity and good grain size like Yitpi, albeit with slightly lower test weight, and is susceptible to pre-harvest sprouting. Trials indicate Gladius to have a lower tolerance to Ally<sup>®</sup> and Hussar<sup>®</sup>. Seed available from AGT (conditional Seed Sharing™ allowed).

**Grenade CL PLUS**<sup>Ⓛ</sup>: an early to mid-maturing line, carrying Clearfield<sup>®</sup> Plus technology, which provides tolerance to label rates of Intervix<sup>®</sup> herbicide. Combines the flexibility of improved weed-management options through use of Intervix<sup>®</sup> with high yield. MR to CCN, MR to stripe rust, R to stem rust, MR–MS to leaf rust, S to yellow leaf spot. Default APW classification NSW. (AGT)

**Harper**<sup>Ⓛ</sup>: derived from Yitpi and Stylet and released by Intergrain in 2013 as a mid–long-season APW variety. MR to CCN and stripe rust but MS to stem and leaf rust and S to yellow leaf spot. Harper is an alternative to Yitpi and Estoc with slightly higher yield. Seed available from Intergrain.

**Justica CL Plus**: APW quality (southern zone). Fully awned, semi-dwarf with midseason maturity. Two-gene tolerance to label rates of Intervix<sup>®</sup> herbicide. MR to stem rust MR–MS to stripe rust, S(p) to leaf rust, MS to CCN, S to yellow leaf spot. Moderately tolerant to boron. Released 2010 and marketed by AGT. EPR \$3.55.

**Kellalac**: APW quality (southern zone). A late-maturity spring wheat, adapted to longer season environments, but intolerant of aluminium. MS–S to stem rust, MR–MS to stripe rust, S to leaf rust, MR to CCN, S to yellow leaf spot. Released 1988.

**Kiora**: AH quality (southern zone). Mid–late-season maturity with high yield potential suited to medium–high-rainfall areas. R–MR to stem and stripe rust, MR–MS(p) to leaf rust, MS to CCN MS–S to yellow leaf spot, MS(p) to black point. Released 2014, tested as VX2485 and marketed by AGT. EPR \$3.25.

Kord CL Plus: AH quality (southern zone). Fully awned semi-dwarf with midseason maturity. Two-gene tolerance to label rates of Intervix® herbicide. MR to stem rust MR–MS to stripe rust, MS to leaf rust, MR to CCN, MS–S to yellow leaf spot. Based on Gladius with very similar adaptation. S–VS to pre-harvest sprouting. Released 2011 and marketed by AGT. EPR \$3.55.

Livingston<sup>Ⓛ</sup>: AH quality. Early-maturing variety, later than H45 but earlier than Ventura and Sunstate. R to leaf rust, MR–MS to stripe and stem rust, MS to yellow leaf spot, S to crown rot, MR–MS to black point. Moderately tolerant–moderately intolerant to RLN (*P. thornei*). Intolerant of acid soils. (AGT).

LongReach Catalina<sup>Ⓛ</sup>: an AH quality, CCN-resistant variety suited to medium–higher rainfall districts across south-eastern Australia. Catalina is earlier flowering by several days than Yitpi and has acceptable physical grain quality. R to stem and leaf rust, MS to stripe rust, MS–S to yellow leaf spot. Long-term yields have been slightly below Yitpi and it has shown sensitivity to Cadence® at recommended label rate and timing. Seed available from Seednet.

LongReach Cobra: AH quality (southern zone). High-yielding early-midseason variety suited to both acid and alkaline soils. R–MR to stem rust, MS–S to stripe rust, MR to leaf rust MR–MS to CCN, MR–MS to yellow leaf spot. Compact plant height, MR to lodging, but S–VS to pre-harvest sprouting. Able to capitalise on above-average rainfall. Notes for South Australia: high yield potential, particularly in the medium–higher rainfall districts. Cobra has good grain size and moderate test weight. Released 2012 and marketed by Pacific Seeds, seed available from Pacific Seeds (conditional Seed Sharing™ allowed). EPR \$3.50.

LongReach Dart<sup>Ⓛ</sup>: AH milling wheat with classification upgrade to APH. With quick maturity suited to later plantings, slightly quicker than Ventura, LongReach Crusader and H45. Suited to Queensland, NSW and north-eastern Victoria. Late plantings may be a useful tool in herbicide-resistance management. Good physical grain, milling and baking quality. R–MR to stem and leaf rusts, MR to stripe rust based on APR. Rated MS to yellow leaf spot. Lower tillering variety, with a long coleoptile and good early seedling vigour. Marketed by Pacific Seeds; seed available from 2013.

LongReach Gauntlet<sup>Ⓛ</sup>: AH quality in NSW. Main-season maturity, similar to Janz and Lang. Fully awned, medium-length coleoptile with good early-seedling vigour, short–medium plant height at maturity. R–MR to stem rust, MR–MS to stripe and leaf rust, MS–S to yellow leaf spot. Performs well in acid soils. (Viterra)

Lancer<sup>Ⓛ</sup>: Slow-maturing spring wheat to help capitalise on earlier planting opportunities. It has APH classification in northern and south-eastern zones (all NSW and Queensland) and has been welcomed by northern growers as a new, long season wheat. Solid grain package with good protein delivery, good grain size and low screenings. MR to stripe rust (based on APR), R to stem rust, R–MR to leaf rust. It has a shorter canopy height with good resistance to lodging and performs well under crown rot pressure. (LongReach)

LongReach Lincoln<sup>Ⓛ</sup>: AH quality. Medium maturity, slightly earlier than Janz. Erect, strong and upright canopy. Suited to southern NSW. MR to stem and leaf rust, R–MR to stripe rust, MR–MS to yellow leaf spot and black point, VS to crown rot and pre-harvest sprouting. (Pacific Seeds)

LongReach Merlin<sup>Ⓛ</sup>: AH milling wheat, with early–mid-season maturity similar to Ventura, Baxter and Drysdale. Suited to NSW and north-eastern Victoria. A Drysdale type with similar growth habit; sister line to LongReach Spitfire, with a similar grain quality package. MR to stripe rust (based on APR), MS to crown rot, moderately tolerant to RLN (*P. thornei*).

LongReach Phantom: AH quality (southern zone). A mid–late-season variety tolerant of boron and acid soil. MS to stem rust, MR to stripe rust, MS–S(p) to leaf rust, MR–MS to CCN, S–VS to yellow leaf spot, MR–MS to black point. Released 2012 and marketed by Pacific Seeds. EPR \$3.80.

**LongReach Scout**<sup>1</sup>: APW in southern NSW. Midseason maturity, similar to Gladius. Good grain package with low screenings and high test weight. R to CCN and leaf rust, MR to stem rust, MS to stripe rust, S-VS to yellow leaf spot. Medium-long coleoptile with good early vigour. Performs well in both alkaline and acid soils. (Pacific Seeds)

**LongReach Spitfire**<sup>1</sup>: APH quality in NSW. Early-midseason maturity, similar to Ventura and Livingston. Good soil disease control against crown rot and RLN (*P. thornei*). Good grain package with low screenings and high test weights. MR to stem and stripe rust, MS to leaf rust, MS-S to yellow leaf spot. Long coleoptile and medium plant height. Performs well in acid soils and may have a protein advantage over other varieties. (Pacific Seeds)

**LongReach Trojan**<sup>1</sup>: APW quality (southern zone). Mid-long-season variety. Semi-dwarf with awns suited to medium-high-rainfall areas. MR-MS to stem rust, MR to stripe rust MR-MS(p) to leaf rust, MS to CCN, MS-S to yellow leaf spot. MR to lodging and moderate tolerance to boron and aluminium. Released 2013, tested as LPB08-1799 and marketed by Pacific Seeds. EPR \$4.

**LongReach Viking**<sup>1</sup>: quality to be confirmed for southern zone but APH in NSW. An awned, semi-dwarf mid-long-season variety suited to medium-high-rainfall areas. MR to stem rust, R-MR to stripe rust, S-VS(p) to leaf rust, R(p) to CCN, MS-S to yellow leaf spot. Similar plant type and early growth habit to Chara, but a similar height to EGA Gregory at maturity. Released 2014, tested as LPB08-1799 and marketed by Pacific Seeds. EPR \$4.25.

**Mace**: AH quality (southern zone). An awned variety of medium height. MR to stem rust, S-VS to stripe rust, MS-S(p) to leaf rust, MR-MS to CCN, MR-MS to yellow leaf spot. Tolerant of boron. Growers of Mace must implement a comprehensive fungicide strategy to control stripe rust. Released 2008, marketed by AGT. EPR \$3.

**Magenta**: APW quality (southern zone). An awned, semi-dwarf, mid-long-season variety. R-MR to stem rust, MS to stripe rust. Leaf coleoptile with good early vigour and tillering capacity. Moderate grain size. Released 2007 and marketed by InterGrain. EPR \$3.

**Merinda**: AH quality (southern zone). An awned, semi-dwarf, main-season variety with white chaff, suited to north-eastern Victoria. R-MR to stem rust, MR-MS to stripe rust, R to leaf rust, S to CCN, MS-S to yellow leaf spot. High straw strength. Released 2007 and marketed by AGT. EPR \$2.50.

**Peake**<sup>1</sup>: released in 2007, medium-short-strawed, mid-maturing (5-6 days earlier than Yitpi) variety that is now generally outclassed for yield by newer varieties. MR-MS to stem and stripe rust, R to leaf rust and CCN, S to yellow leaf spot. Tolerant to boron. Peake has AH quality and can produce small grain under dry spring conditions. Available from Seedcell.

**Sentinel3R**<sup>1</sup>: ASW quality in NSW. Later maturing than Janz. R-MR to stem and stripe rust, R to leaf rust, MS-S to crown rot, S to common root rot, MS to yellow leaf spot, R-MR to black point, S to pre-harvest sprouting, R to shattering. Short coleoptile. (Seednet)

**Shield**: AH quality (southern zone). A white, fully awned, early-midseason variety. R-MR to stem rust, MR to stripe rust, R to leaf rust, MR to CCN, MS-S yellow leaf spot. Short-medium plant height with a short coleoptile. Moderate tolerance to acid soils. Released 2012 and marketed by AGT. EPR \$3.25.

**Suntop**<sup>1</sup>: A main-season line well adapted to NSW, showing high and stable yields from areas of low-high yield potential. Quicker maturing than EGA Gregory, similar in maturity to Janz. MR to stem rust, R-MR to stripe rust, R to leaf rust, S-MS to yellow leaf spot, MS to crown rot. It has moderate tolerance to acid soils and RLN (*P. thornei*). Suntop has a final APH quality classification in northern NSW. AGT has enabled farmer-to-farmer sales of this variety but only from the initial purchaser of the seed to the next grower (Seed Sharing™).

Wallup<sup>®</sup>: APH quality classification in NSW. A midseason wheat with very good grain-processing quality characteristics and high straw strength. Moderate coleoptile length. Best suited to environments of medium yield potential, but it has not performed as well in Mallee environments. Intolerant of toxic levels of soil boron and acid soils. Rated MR to CCN, R–MR to stem rust, MR–MS to stripe and leaf rust, MS–S to yellow leaf spot, MR to pre-harvest sprouting and black point. Expresses low levels of screenings. (AGT)

Yitpi: AH quality (southern zone). White, fully awned semi-dwarf that has dominated production in low-rainfall areas of Victoria with its high flexibility of sowing time, adaptation to stress and good physical grain quality. S to stem rust, MR–MS to stripe rust, S(p) to leaf rust, MR to CCN, S–VS to yellow leaf spot. Boron tolerant, large grain and low screenings. Suits low–medium-rainfall areas. Registered 2000 and marketed by Seednet. EPR \$1.

Young: AH quality (southern zone). An early–mid-maturing variety suited to medium–low-rainfall zones. R–MR to stem rust, MS to stripe and leaf rust, R to CCN, MR–MS to yellow leaf spot. Tolerant of acid soils but has small grain size. An option for wheat-on-wheat and tight wheat rotations. Registered 2005 and marketed by Seednet. EPR \$1.70.

### *Biscuit wheat*

Barham: ASF1 quality (southern zone). Awnless midseason variety suited to medium–high-rainfall zones or irrigation. MR–MS to stem rust, S to stripe rust, MR–MS to leaf rust, MS to CCN, MS–S to yellow leaf spot. A replacement for Bowie, suited to sweet biscuit manufacture. Registered 2006 and marketed by Seednet.

LongReach Gazelle<sup>®</sup>: ASF1 quality (southern zone). High-yielding, mid–late-season variety suited to medium–high-rainfall zones and irrigation. MR to stem, stripe and leaf rust, S to CCN, MS–S to yellow leaf spot. Released 2012 and marketed by Pacific Seeds. EPR \$4.00.

LongReach Impala<sup>®</sup>: ASF1 quality (southern zone). High-yielding, early–midseason variety suited to medium-rainfall zones in Victoria. MR to stem and stripe rust MR, S–VS(p) to leaf rust, S to CCN, MS–S to yellow leaf spot. Released 2012 and marketed by Pacific Seeds. EPR \$3.50.

Yenda: ASF1 quality (southern zone). Awned, mid–late-season variety suited to medium–high-rainfall zones or irrigation. R to stem rust, S to stripe rust and CCN, MR–MS to yellow leaf spot. Very high straw strength. Released 2006 by AGT and marketed by Seednet. EPR \$2.

### *Feed–dual purpose*

Manning<sup>®</sup>: feed quality (southern zone). A dual-purpose, white grain with high yield potential suited to zones with longer growing season and irrigation. MR to stem rust, R–MR to stripe rust, R–MR leaf rust, S to CCN, MR–MS to yellow leaf spot, R to BYDV. Bred by CSIRO/GRDC (as CS9274.33), released 2013 and marketed by GrainSearch. EPR \$3.50.

Naparoo: feed quality (southern zone). A white-grained, awnless, long-season winter wheat suited to hay production or grazing. R–MR to stem rust, MR to stripe rust, S to leaf rust, MS to yellow leaf spot. Released 2007. Marketed by AGT. EPR \$2.50.

SF Adagio: feed quality (southern zone). An awned, red winter wheat. Mid–long-season variety for high-rainfall zones and irrigation. Adagio is suitable for dual-purpose applications when early sowing is possible. S–VS to stem rust, R–MR to stripe rust, MS(p) to leaf rust, MR–MS to yellow leaf spot. Released 2014, marketed by AGF Seeds. EPR \$3.60.

SF Ovalo: feed quality (southern zone). Awnless, red winter wheat. Long-season variety for high-rainfall zones and irrigation. Suitable for dual-purpose applications when early sowing is possible. S to stem rust, R to stripe rust, MS(p) to leaf rust, MR to yellow leaf spot. Bred by RAGT (France); released 2014 and marketed by Seedforce. EPR \$4.

SF Scenario: feed quality (southern zone). Awnless, red winter wheat. Long-season variety with similar maturity to Frelon and a direct replacement for Frelon and Amarok. MS-S to stem rust, MR to stripe rust, S(p) to leaf rust, MS to yellow leaf spot. Bred by RAGT, released 2013 and marketed by AGF Seeds. EPR \$3.60.

SQP Revenue: feed quality (southern zone). A red-grained winter wheat suited to longer growing season zones and irrigation. R-MR to stem rust, R to stripe rust, S(p) to leaf rust, S to CCN, MS to yellow leaf spot. Has good early vigour and stands well with good head retention. Bred by AusGrainz and CSIRO (as CSIRO 95102.1), released 2009 and marketed by GrainSearch. EPR \$3.50.

## 2.3 Planting seed quality

### 2.3.1 Seed size

Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if seed is undamaged, stored correctly and from a plant that had adequate nutrition. Seed should not be kept from paddocks that were rain-affected at harvest. Seed grading is an effective way to separate good quality seed of uniform size from small or damaged seeds and other impurities, such as weed seeds.

Seed size is also important—the larger the seed, the greater the endosperm and starch reserves. Although size does not alter germination, bigger seeds have faster seedling growth, a higher 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. Sowing rate needs to vary according to the 1000-grain weight for each variety, in each season, in order to achieve desired plant densities.<sup>13</sup>

To measure 1000-grain weights, count out 10 lots of 100 seeds, then weigh. When purchasing seed, remember to request the seed analysis certificate, which includes germination percentage, and the seed weight of each batch where available.

The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface (see Figure 3). Coleoptile length is an important characteristic to consider when planting a wheat crop, especially in drier seasons when sowing deep to reach soil moisture. The results of 2008 research at three sites are presented in the NSW DPI publication: [Coleoptile length of wheat varieties](#).

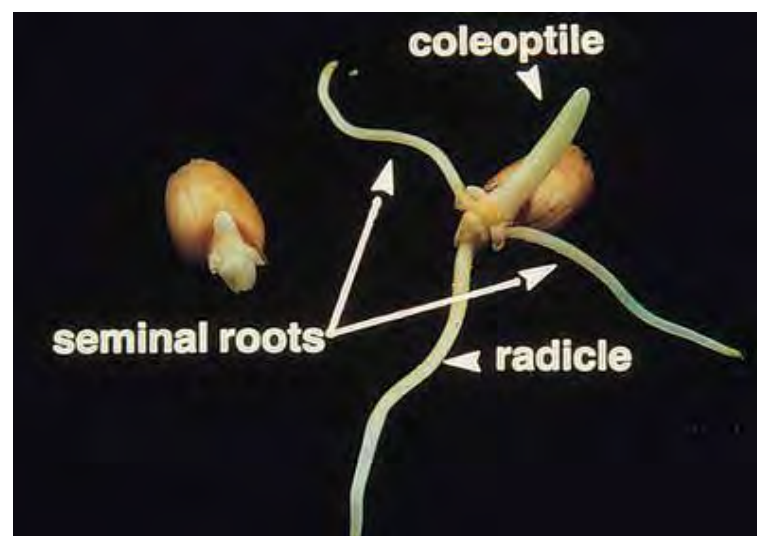


Figure 3: The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface. (Photo: David L. Hansen, University of Minnesota)

<sup>13</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)



For wheat seed to emerge successfully from the soil, the seed should never be planted deeper than the coleoptile length. Sowing varieties with short coleoptile lengths too deep can cause poor establishment, because the shoot will emerge from the coleoptile underground and it may never reach the soil surface.

Coleoptile length is influenced by several factors, including variety, seed size, temperature, low soil water and certain seed dressings, such as those with the active ingredient triadimenol or flutriafol. Trifluralin and several Group B pre-emergent chemicals can also affect coleoptile length. Growers should read the label when using any seed-dressing fungicide for wheat, in order to see what effect it may have on coleoptile length.<sup>14</sup>

### 2.3.2 Seed germination and vigour

Seed germination and vigour greatly influence 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<sup>15</sup>

Seed vigour affects the level of activity and performance of the seed or seed lot during germination and seedling emergence. Loss of seed vigour is related to a reduction in the ability of the 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 (a few days) or more slowly (years), depending on genetic, production and environmental factors not fully understood. The culmination 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.<sup>16</sup>

For more information on factors affecting germination, see [GrowNotes Wheat South Section 4. Plant growth and physiology](#).

Request a copy of the germination and vigour analysis certificate from your supplier for purchased seed. For seed stored on-farm, you can send a sample to a laboratory for analysis. For a list of Australian International Seed Testing Authority laboratories, see [Australian Seeds Authority](#).

Although a laboratory seed test for germination should be carried out before seeding to calculate seeding rates, 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

<sup>14</sup> J Pumpa, P Martin, F McCrae, N Coombes (2013) Coleoptile length of wheat varieties. NSW Department of Primary Industries, Feb. 2013, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/459006/Coleoptile-length-of-wheat-varieties.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/459006/Coleoptile-length-of-wheat-varieties.pdf)

<sup>15</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

<sup>16</sup> ISTA (1995) Understanding seed vigour. International Seed Testing Association, <http://www.seedtest.org/upload/prj/product/UnderstandingSeedVigourPamphlet.pdf>

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 the seeds as 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.
- Keep soil moist but not wet, as 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 for calculating seeding rates.<sup>17</sup>

### 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.

Seedborne disease generally cannot be identified from visual inspection, so requires laboratory testing.<sup>18</sup>

### 2.3.3 Seed purity

Seed impurity can occur from contamination through harvest, storage and machinery. Measurement of seed impurity will be included in a seed purity certificate. Varieties that have been retained for multiple generations have an increased risk of seed impurity, with multiple chances for contamination events and build-up. Ensuring that seed comes from clean, pure and even crops is imperative, and seed purity tests should be carried out. Growers should conduct paddock audits prior to harvest to establish which paddocks best meet these criteria.

With dramatic increases in herbicide resistance, growers need to take seed purity into account when selecting paddocks for seed wheat. Ryegrass and black oats frequently appear in harvested grain samples and have the potential to infest otherwise clean paddocks.

### Sunvale case study

Research shows that impurity (variety contamination) is quite common in commercial Sunvale<sup>®</sup> crops. Pure Sunvale<sup>®</sup> remains moderately resistant to stripe rust and does not require in-crop fungicide management. However, if the Sunvale<sup>®</sup> seed has been contaminated with a stripe-rust-susceptible variety, as evident in 16 of the commercial seed lots, then stripe rust may be prevalent and warrant chemical control. A simple variety mix-up (e.g. Sunvale 15<sup>®</sup>) also appears to be an issue, as well as variety misidentification, which meant that the crop did not have adult plant resistance to stripe rust.

<sup>17</sup> GRDC (2011) Saving weather damaged grain for seed, northern and southern regions. Retaining Seed Fact Sheet, GRDC, January 2011, [http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC\\_FS\\_RetainingSeed2.pdf](http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC_FS_RetainingSeed2.pdf)

<sup>18</sup> GRDC (2011) Saving weather damaged grain for seed, northern and southern regions. Retaining seed Fact Sheet, GRDC, January 2011, [http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC\\_FS\\_RetainingSeed2.pdf](http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC_FS_RetainingSeed2.pdf)

### More information

[GRDC Podcasts: Driving agronomy. Variety checks increase](#)

Researchers were not surprised that high levels of impurity were observed in commercial Sunvale<sup>®</sup> lots, given that it is a 17-year-old variety. Growers need to take care in ensuring variety purity and correct identification of seed lots for planting. This study also emphasises the value of growers conducting careful observation of head type and the pattern of disease distribution in crops that are showing unexpected disease reactions.

This is the first report of seed impurity being determined as the cause of unexpected stripe rust responses within a wheat variety. This situation is unlikely to be unique to Sunvale<sup>®</sup> and may explain mixed reports of stripe rust levels commercially in more recently released, moderately resistant varieties such as EGA Gregory<sup>®</sup>.<sup>19</sup>

The GRDC has invested in the development of a new commercial, cost-effective DNA test to identify the variety and purity of wheat and barley samples.

### 2.3.4 Seed storage

The aim of storage is to preserve the viability of the seed for future sowing and maintain its quality for market. A seed is a living organism that releases moisture as it respire. The ideal storage conditions are as follows:

- Temperature <15°C. High temperatures can quickly reduce seed germination and quality. This is why germination and vigour testing prior to planting is so important.
- Moisture control. Temperature changes cause air movements inside the silo, carrying moisture to the coolest parts of the seed. Moisture is carried upwards by convection currents in the air; these are 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, which slows the rate of deterioration of seed with 12.5–14% moisture. Aeration markedly reduces grain temperature and evens out temperature differences that cause moisture movement (Figure 4).
- No pests. Temperature <15°C stops all major grain insect pests from breeding, slowing their activity and reducing damage.<sup>20</sup>

<sup>19</sup> S Simpfendorfer, A Martin, M Sutherland (2012) Seed impurity undermines stripe rust resistance. 16th Australian Agronomy Conference. Australian Society of Agronomy/the Regional Institute Ltd, [http://www.regional.org.au/au/asa/2012/disease/8325\\_simpfendorfer.htm#TopOfPage](http://www.regional.org.au/au/asa/2012/disease/8325_simpfendorfer.htm#TopOfPage)

<sup>20</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)



Figure 4: Aeration markedly reduces grain temperature. (Photo: Kondinin Group)

### 2.3.5 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 Pivot Fertilisers has shown that the tolerance of crop species to ammonium fertilisers placed with the seed at sowing is related to the fertiliser product (ammonia potential and osmotic potential), application rate, row spacing and equipment used (such as a disc or tine), and soil characteristics such as moisture content and texture.<sup>21</sup>

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–phosphorus products) or by pre- or post-plant application (N-only products). For fertilisers with lower ammonium content such as mono-ammonium phosphate, adhere to the safe rate limits set for the crop species and soil type.<sup>22</sup>

High rates of N fertiliser applied at planting in contact with, or close to, the seed may severely reduce seedling emergence. If a high rate of N is required, 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). Rates should be reduced by 50% for very sandy soil and increased by 30% for heavy-textured soils or if soil moisture conditions at planting are excellent.<sup>23</sup> See Tables 4 and 5 for more detail.

Nitrogen rates should be adjusted when using narrow points and press-wheels or disc seeders. When moisture conditions are marginal for germination, growers need to reduce N rates if fertiliser is to be placed with, or close to, the seed.

<sup>21</sup> Incitec Pivot Fertilisers (2014) Nitrogen fertiliser placement and crop establishment. Incitec Pivot Ltd, <http://bign.com.au/Big%20N%20Benefits/Nitrogen%20Fertiliser%20Placement%20and%20Crop%20Establishment>

<sup>22</sup> Incitec Pivot Fertilisers (2014) Nitrogen fertiliser placement and crop establishment. Incitec Pivot Ltd, <http://bign.com.au/Big%20N%20Benefits/Nitrogen%20Fertiliser%20Placement%20and%20Crop%20Establishment>

<sup>23</sup> Incitec Pivot Fertilisers (2014) Nitrogen fertiliser placement and crop establishment. Incitec Pivot Ltd, <http://bign.com.au/Big%20N%20Benefits/Nitrogen%20Fertiliser%20Placement%20and%20Crop%20Establishment>

Table 4: Approximate safe rates (kg/ha) of nitrogen as urea, mono-ammonium phosphate or di-ammonium phosphate with the seed of cereal grains if the seedbed has good soil moisture (at or near field capacity)

SBU, Seedbed utilisation is the amount of the seedbed over which the fertiliser has been spread; SBU% = (width of seed row/row spacing) x 100. Contact your agronomist or fertiliser supplier for other details on other blends

Soil texture	Seed spread 25mm			Seed spread 50mm		
	Row spacing: 180mm					
SBU:	14%	11%	8%	29%	22%	17%
Light (sandy loam)	20	15	11	40	30	22
Medium-heavy (loam to clay)	25	20	15	50	40	30

Table 5: Urea (46% nitrogen) application rates (kg/ha) for wheat and barley on different soil types under good soil moisture conditions and different seedbed utilisation

	Seedbed utilisation rate (%)							
	5	10	15	20	25	30	40	50
Heavy soil	55	60	65	70	75	80	95	105
Medium soil	45	50	55	60	65	70	80	90
Light soil	25	30	35	40	45	50	60	65

For more information, see [GrowNotes Wheat South Section 3. Planting](#) and [Section 5. Nutrition and fertiliser](#).

### More information

[RMS Agricultural Consultants: Fertiliser toxicity](#)

## SECTION 3

# Planting

## 3.1 Seed treatments

Seed treatments are applied to seed to control diseases such as smuts, bunts or rust, and insects. When applying seed treatments, always read the chemical label and calibrate the applicator. Seed treatments are best used in conjunction with other disease-management options such as crop and paddock rotation, clean seed, and resistant varieties, especially when managing diseases such as stripe rust.

There are risks associated with using 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

If there is a delay in emergence due to decreased vigour, it increases exposure to pre-emergent attack by pests and pathogens, or to soil crusting; this may lead to a failure to emerge. The risk of emergence failure increases when seed is sown too deeply or into a poor seedbed, especially in varieties with shorter coleoptiles. As the amount of certain fungicides increases, the rate of germination slows (Figure 1).

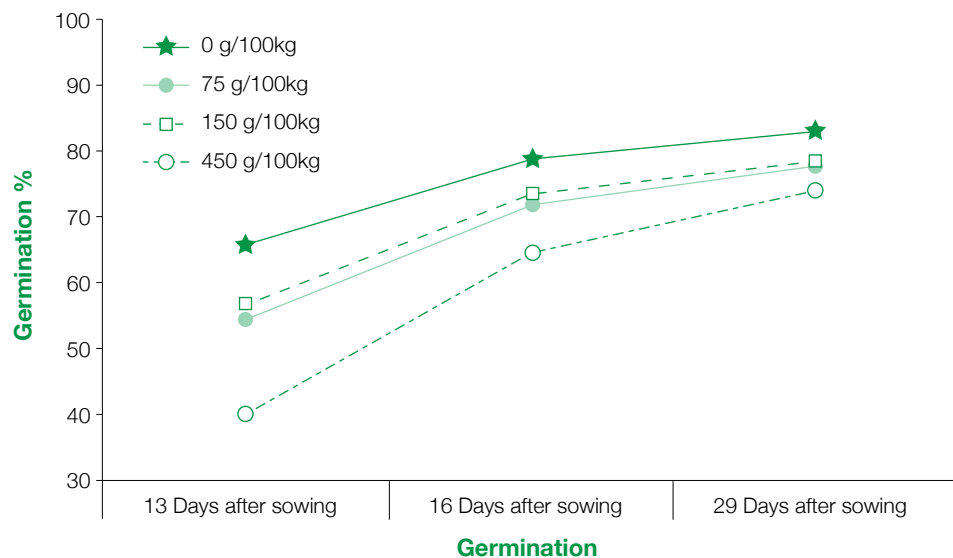


Figure 1: Impact of seed-treatment fungicide on the rate of germination. (Source: based on P Cornish 1986)

Some seed treatments contain azole fungicides (triadimenol and triadimefon). Research has found that these seed treatments can reduce coleoptile length, and that the reduction increases as the rate of application increases.<sup>1</sup>

<sup>1</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

Product registrations change over time and may differ between states and between products containing the same active ingredient. The registration status for the intended use pattern in your state must be checked on the current product label prior to use.

### 3.1.1 Choice of seed or in-furrow treatments

The principal reason for using a fungicide at sowing for wheat crops has been for the control of smuts, but with the increased incidence of stripe rust in recent years, fungicide is being applied both to the seed and in-furrow. Jockey® (fluquinconazole) seed dressing is being used for stripe rust mostly in lower rainfall areas or Impact® (flutriafol) in-furrow is used for stripe rust in medium- and high-rainfall areas where the risk is greater.

If growers think that they may have a problem with seed-borne infection, it is recommended they have the seed tested by the [Cereal Pathology Subprogram, Plant Health and Biosecurity](#) at the South Australian Research and Development Institute.<sup>2</sup>

## Videos

[Optimal flowering Part 1](#)

[Optimal flowering Part 2](#)

[Early sown wheat series](#)

## 3.2 Time of sowing

Choosing the optimal planting time for wheat involves compromise. Planting early will increase the chance of frost damage at flowering. With late-maturing varieties, it can also increase the bulk of crops, i.e. vegetative growth, and lead to stored soil water being used before flowering. In early-maturing varieties, sowing late may reduce the bulk of the crop because development is hastened, as well as reduce rooting depth. This can lead to reduced yield potential and reduced access to deeper moisture and nutrients.

Key points:

- Early sowing can accelerate establishment and make full use of the available moisture and nutrients but can increase the risk of frost during critical growth stages and haying-off in a dry finish.
- Early-sown crops can have a larger root system that better enables them to handle dry conditions and forage for nutrients.
- Flowering time of wheat is controlled by the interaction of several factors, including temperature, day length and cold requirement.
- Most Australian wheat varieties flower in response to the accumulation of warm temperatures. Many varieties also have a cold temperature requirement, i.e. vernalisation, which is important in some winter wheats, and some varieties flower in response to longer days.
- To minimise risk, varieties with a range of flowering dates and maturities should be sown, provided other criteria such as disease resistance are also met.
- The relationship between sowing date and crop development can interact with disease development and nutrition management.
- Late sowing can increase the severity of most root diseases. Early sowing can increase the severity of several leaf diseases (e.g. stem rust) due to the bulk of growth. Rusts are not consistently affected by sowing time.<sup>3</sup>
- Late-sown crops that emerge in colder, wetter conditions are more prone to leaf diseases such as yellow leaf spot, due to slower early growth.

Timing of wheat planting is critical and high soil temperatures can reduce establishment. The ideal temperature range for wheat germination is 12°–25°C, but germination will occur between 4°C and 37°C.<sup>4</sup> Different varieties have been bred to suit different

<sup>2</sup> H Wallwork (2015) Cereal seed treatments 2016. South Australian Research and Development Institute/GRDC, [http://pir.sa.gov.au/\\_data/assets/pdf\\_file/0005/237920/cerealseedtreat2016.pdf](http://pir.sa.gov.au/_data/assets/pdf_file/0005/237920/cerealseedtreat2016.pdf)

<sup>3</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

<sup>4</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

planting times, and varieties differ in their ability to achieve high yield from different sowing times.<sup>5</sup> The optimal sowing date results in flowering and grain-filling occurring when risk of frost and heat is minimised (Figure 2).

A season that breaks in April is ideal because of the opportunity to use all options. Long-season (winter) wheat varieties are sown first at the optimum time of mid-late April through to mid-May (south-western and north-western Victoria), and midseason varieties follow in May–June. If the break is later, the same principle applies, except that in an extremely late season, farmers would forego sowing long-season wheats.



Figure 2: The optimal sowing date results in flowering and grain-filling occurring when frost and heat risk is minimised.

Recent experience has demonstrated the benefit of sowing a portion of the crop dry if a seasonal break has not been received by late April. These crops germinate rapidly when rain falls and generally make the best use of limited growing-season rainfall.<sup>6</sup>

Four years of trials have demonstrated that early sowing of wheat (late April to mid-May) is essential in order to achieve the high yields on offer in south-western Victoria. However, sowing early in the high-rainfall zone (HRZ) is not without challenges and, to be successful, needs to fit into a farm-management system designed to manage trade-offs with weed control, frost risk, waterlogging and disease.

Many of the management decisions that affect crop yields in rainfed cropping systems are made months or years before a crop is planted. The management factors that most contribute to yield and interact with sowing time and cultivar choice are:

- seeding system
- crop rotation
- summer fallow management
- time of sowing and cultivar selection
- dual-purpose grazing
- foliar disease management
- nitrogen (N) management

## More information

[GRDC Update Papers: Managing the risks of early sown wheat in South West Victoria](#)

[GRDC Update Papers: Early sowing in Victoria 2014](#)

[Australian Agronomy Conference: Turning sowing times on their head—spring sown winter habit canola and wheat in a mixed farming system](#)

[Australian Agronomy Conference: Wheat time of sowing and cultivar selection can be used to manage risk in low rainfall southern Australia](#)

[Australian Grain: Early sowing adds yield to slow-maturing wheats](#)

[Australian Agronomy Conference: Time of sowing affects small grain screenings in wheat in a dry season](#)

[Riverine Plains Inc.](#)

[GRDC Update Papers: Wheat variety response to sowing time](#)

<sup>5</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

<sup>6</sup> Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>



Each of these factors forms part of a package that allows early sowing to deliver high yields in the HRZ. <sup>7</sup>

Varieties differ in the time they take from sowing to flowering. Late-sown (quicker maturing) varieties take fewer days to flower than early-sown (late-maturing) varieties. This difference is more marked from early sowings (April) than from late sowings (July). <sup>8</sup>

Genes control the plant's developmental responses to the accumulation of temperature, daylength and cold requirement (vernalisation). Various combinations of genes are present in Australian wheat varieties, which result in a wide spectrum of responses to temperature and daylength.

The products of the vernalisation genes and photoperiod genes almost certainly interact to promote or delay flowering (Figure 3). Australian wheat breeders now have tools to improve identification of the vernalisation and photoperiod genes in wheat varieties.

To ensure that the crop flowers at the optimal time, an understanding is required of how sowing time affects flowering time as well as the frequency of frosts and high temperatures. <sup>9</sup>

## More information

[GRDC Fact Sheets: Time of sowing](#)

[GRDC Media Centre: Early sowing delivers benefits in LRZ](#)



Figure 3: EGA Gregory wheat in flower. Most Australian wheat varieties flower in response to the accumulation of warm temperatures. (Photo: Penny Heuston)

### 3.2.1 Why sow early?

Advantages of early sowing include:

- yield benefits in seasons with hot and dry finishes, particularly where frost is not a major problem

<sup>7</sup> J Hunt *et al.* (2015) Mud, weeds, frost, sheep and disease—managing the risks of early-sown wheat in South West Victoria. GRDC Update Papers, 27 August 2015, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Managing-the-risks-of-early-sown-wheat-in-South-West-Victoria>

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

<sup>9</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

- better establishment from early sowing providing competitive crops for weed control
- longer grain-filling period in varieties that flower earlier
- increased biomass for increased yield potential in a wet season
- deeper roots than late-sown crops, allowing access to moisture later in the season
- less yield loss from crown rot than in later sown crops
- logistical benefits
- less risk of several root diseases
- adaptation of winter varieties to early sowing

Disadvantages of early sowing include:

- risk with dry sowing due to a false break, especially on heavier soil types
- some early varieties not being suited to early sowing and flowering very early, resulting in reduced biomass and root depth at flowering, and reduced potential yields
- greater risk of frost damage in frost-prone areas for varieties that flower earlier
- increased risk of haying-off as biomass increases, especially in drier springs
- greater risk of a number of leaf diseases and take-all
- tall crops at greater risk of lodging
- less opportunity for knockdown or mechanical weed control for herbicide-resistance management
- increased chance of weed problems and poor establishment with complete reliance on in-crop weed control<sup>10</sup>

### More information

[GRDC Fact Sheet: Early-sowing wheat in Victoria](#)

[GRDC Update Papers: Sowing early in 2014—how did it work?](#)

## in focus

### 3.2.2 Sowing early in 2014—how did it work?

#### *Take home messages*

Despite widespread stem frost in 2014, time of sowing trials in South Australia (SA) indicated that the highest yields still came from mid-late April sowing.

Based on one year of data, Trojan<sup>®</sup> (mid-maturing) complements Mace<sup>®</sup> (fast-maturing) in a cropping program and allows growers to sow earlier and achieve higher yields (16%) than with Mace alone sown in its optimal window.

Existing slow-maturing wheat cultivars from other states are poorly adapted to most regions in SA.

For growers in frosty environments wishing to sow before about 20 April, EGA Wedgetail<sup>®</sup> is the safest option evaluated in these trials, but yields are likely to be less than with Mace<sup>®</sup> sown in its optimal window.

#### *Background*

In SA, the time at which wheat flowers is very important in determining yield (Figure 4). With farm sizes increasing and sowing opportunities decreasing, it is difficult to get wheat crops established so that they flower during the optimal period for yield. Although no-till and dry sowing have been used successfully in SA so that a greater area of the crop will flower on time, an opportunity exists to take advantage of rain in March and April to begin sowing crops earlier than currently practiced. This tactic complements dry sowing. Earlier sowing is now possible with modern no-till techniques, summer fallow

<sup>10</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

management, and cheaper insecticides and fungicides to protect against the diseases associated with early sowing.

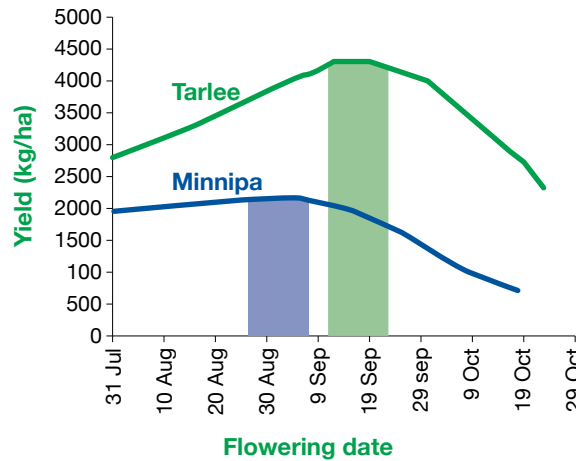


Figure 4: Relationship between flowering time and yield at Minnipa and Tarlee. Optimal flowering periods are highlighted by light-grey and dark-grey boxes. Curves are derived from APSIM from 120 years of climate data and with a yield reduction for frost and extreme heat events. Optimal flowering periods are late August–early September at Minnipa, and mid-September at Tarlee.

However, in the last few decades wheat breeding has focused on mid-fast-maturing varieties, which are only suited to sowing in late April–May. Sowing earlier than is currently practiced requires cultivars that are not widely grown in SA, and which are much slower to mature, either through having a strong vernalisation–cold requirement (winter wheats) or strong photoperiod–daylength requirement (slow-maturing spring wheats, Figure 5).

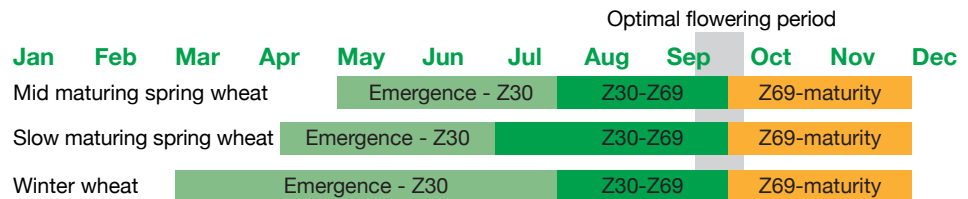


Figure 5: Diagram showing pattern of development in winter and slow-maturing spring wheat relative to mid-maturing spring (most currently grown varieties in SA are mid-fast). When sown at their optimal times, they all flower during the optimal period in a given environment. Winter wheats also have a very flexible sowing window and, if well adapted, will flower during the optimum period in a given environment from a broad range of sowing dates. Zadoks growth stages are indicated.

GRDC-funded research in New South Wales (NSW) has demonstrated that slow-maturing varieties sown early yield more than mid-fast varieties sown later, when they flower at the same time. This is because early sowing increases rooting depth and water use, reduces evaporation and increases transpiration efficiency. Early sowing of slow-maturing varieties is a way of increasing yield potential with very little initial investment.

APSIM modelling indicates that, even with SA’s Mediterranean climate, adoption of slow-maturing varieties to allow early sowing has the potential to increase whole-farm wheat yield, particularly in mid-high-rainfall zones (Table 1). GRDC has funded a series of trials across rainfall zones to evaluate the suitability of early sowing in SA.

Table 1: Average farm wheat yields from 50 years of simulation at different locations in South Australia

Current practice: mid-fast varieties sown from mid-May, including dry sowing; early sowing: addition of a slow-maturing variety to the cropping program, which can be planted from 1 April but is only when planting opportunities arise (~60% of years)

Location	Average farm yield (t/ha)		Yield benefit from early sowing	
	Current practice	Early sowing		(%)
Conmurra	4.0	6.1	2.1	53%
Cummins	3.3	4.0	0.8	24%
Minnipa	2.1	2.2	0.1	5%
Port Germein	1.9	2.1	0.2	11%
Tarlee	3.5	4.0	0.5	14%

### Methodology

GRDC early-sowing trials in SA are at five locations (Cummins, Minnipa, Port Germein, Tarlee and Conmurra), each with three times of sowing (aimed at mid-April, early May, late May) and 10 wheat lines (6 commercial; 4 near-isogenic lines, or NILs, in a Sunstate background). The commercial lines are described in Table 2. The Hart Field Site Group planted a similar early-sowing trial, and there are trials funded by *South Australian Grain Industry Trust Fund* (SAGIT) evaluating different wheat lines for early sowing in the Mid North and Upper Yorke Peninsula.

Table 2: Commercial wheat varieties used in the South Australian trials at Cummins, Minnipa and Port Germein

NIL, Near-isogenic line

Variety	Maturity	Comments
Manning <sup>†</sup> (Conmurra only)	Very slow winter (very strong vernalisation, unknown photoperiod)	White feed. Resistant to <i>Barley yellow dwarf virus</i> but adapted only to environments with a very long, cool growing season
SQP Revenue <sup>†</sup> (Conmurra only) (NIL match: W46A)	Slow winter (strong vernalisation, unknown photoperiod)	Red feed. Also adapted to long, cool growing seasons, it is widely grown in SW Victoria and SE SA
EGA Wedgetail <sup>†</sup> (NIL match: W8A)	Mid-maturing winter (strong vernalisation, moderate photoperiod)	APW (default in SA), APH in NSW. Early-sowing and dual-purpose standard in southern NSW and an excellent grain-only option. May be too slow in most of SA, has only APW quality and can be quite intolerant of problems associated with alkaline soils (cereal cyst nematode, boron, aluminium).
Rosella (NIL match: W7A)	Fast-maturing winter (strong vernalisation, weak photoperiod)	ASW. Slightly faster than Wedgetail <sup>†</sup> , and trials in Victoria show better adaption to alkaline soils. However, being 29 years old, it is at a distinct yield disadvantage compared with modern spring wheats
EGA Eaglehawk <sup>†</sup> (NIL match: W16A)	Very slow-maturing spring (moderate vernalisation, very strong photoperiod)	APW (default in SA), APH in NSW. Very slow-maturing, photoperiod-sensitive spring wheat that will flower at the same time as Wedgetail <sup>†</sup> from a mid-April sowing but will reach Zadoks growth stage 30 about 3 weeks earlier, and therefore not as suited to grazing
Forrest <sup>†</sup> (NIL match: W16A)	Very slow-maturing spring (weak vernalisation, very strong photoperiod)	APW. Very slow-maturing, photoperiod-sensitive spring wheat that performs well in higher yielding environments
Bolac <sup>†</sup> (Tarlee and Conmurra only)	Slow-maturing spring (moderate vernalisation, moderate photoperiod)	AH. Bred for the HRZ of SW Victoria but has performed well when sown early in the low-rainfall regions of the western Riverina in NSW
Estoc <sup>†</sup>	Mid-maturing spring (weak vernalisation, strong photoperiod)	APW. Probably the slowest maturing recently released variety with good adaptation to SA. Not suited to sowing much before 20 April in most environments

Variety	Maturity	Comments
Trojan <sup>†</sup>	Mid-fast-maturing spring (moderate vernalisation, moderate photoperiod)	APW. Has demonstrated good adaption to SA and has an unusual photoperiod gene, which may allow it to be sown in late April and flower at the optimal period
Mace <sup>†</sup> (NIL match: Sunstate)	Fast-maturing spring (weak vernalisation, weak photoperiod)	AH. SA main-season benchmark, and in the trial as a control from a mid-late May sowing
Cobra <sup>†</sup> (Conmurra only)	Fast-maturing spring (weak vernalisation, weak photoperiod)	AH. Very similar maturity to Mace <sup>†</sup> but, based on NVT results, may outyield it in higher yielding environments

### Results

Results from all experiments are presented in Table 3. At four of five sites, Trojan<sup>†</sup> sown in mid-late April was the highest or equal highest yielding treatment. Slow-maturing cultivars bred in other states (e.g. EGA Wedgetail<sup>†</sup>, EGA Eaglehawk<sup>†</sup> and Rosella) showed poor adaptation to all sites.

Table 3: Grain yield for five of six early-sowing trial sites in South Australia in 2014 (results for Conmurra not available at time of preparation)

FA, Treatments known to have been affected by frost

Location	Cultivar	Time of sowing		
		11 April	13 May	28 May
<b>Cummins</b>				
	EGA Wedgetail <sup>†</sup>	4.0	2.9	3.7
	Rosella	4.0	4.1	2.5
	EGA Eaglehawk <sup>†</sup>	3.8	2.9	2.7
	Estoc <sup>†</sup>	4.3	4.7	3.8
	Trojan <sup>†</sup>	4.9	5.0	4.4
	Mace <sup>†</sup>	2.6 (FA)	5.1	4.1
	<i>P</i> -value	<0.001		
	<i>I.s.d.</i> ( <i>P</i> = 0.005)	0.6		
<b>Minnipa</b>				
	EGA Wedgetail <sup>†</sup>	2.9	2.2	2.1
	Rosella	2.7	2.4	2.1
	EGA Eaglehawk <sup>†</sup>	3.0	1.8	1.7
	Estoc <sup>†</sup>	4.0	2.7	2.6
	Trojan <sup>†</sup>	4.6	3.1	3.0
	Mace <sup>†</sup>	3.7	3.0	2.8
	<i>P</i> -value	<0.001		
	<i>I.s.d.</i> ( <i>P</i> = 0.005)	0.2		
<b>Port Germein</b>				
	EGA Wedgetail <sup>†</sup>	2.5	1.9	1.7
	Rosella	2.2	1.7	1.6
	EGA Eaglehawk <sup>†</sup>	3.0	2.1	1.9
	Estoc <sup>†</sup>	4.4	3.5	3.4
	Trojan <sup>†</sup>	5.2	4.2	3.9
	Mace <sup>†</sup>	4.3	4.3	3.7
	<i>P</i> -value	<0.001		
	<i>I.s.d.</i> ( <i>P</i> = 0.005)	0.5		
<b>Hart</b>				
	EGA Wedgetail <sup>†</sup>	4.5	4.0	3.0

Location	Cultivar	Time of sowing			
	Rosella	4.3	3.7	2.8	
	Trojan <sup>(1)</sup>	5.7	5.3	3.7	
	Mace <sup>(1)</sup>	3.9 (FA)	4.7	3.3	
	RAC1843 (Hatchet CL Plus <sup>(1)</sup> )	0.8 (FA)	3.6	3.5	
	<i>P</i> -value	<0.001			
	<i>I.s.d.</i> ( <i>P</i> = 0.005)	0.3			
Tarlee	Cultivar	14 April	29 April	12 May	30 May
	Rosella	5.5	5.4	4.6	3.5
	Bolac <sup>(1)</sup>	6.1	6.1	4.6	3.7
	Trojan <sup>(1)</sup>	6.6	7.4	6.1	4.6
	Mace <sup>(1)</sup>	4.1 (FA)	7.4	6.4	5
	<i>P</i> -value	<0.001			
	<i>I.s.d.</i> ( <i>P</i> = 0.005)	0.6			

### Putting early sowing into practice in SA

Based on the 2014 trial data, growers in SA could improve whole-farm yields by including Trojan<sup>(1)</sup> in their cropping program to complement Mace<sup>(1)</sup> (Figure 6). Trojan<sup>(1)</sup> has an unusual-photoperiod sensitivity allele that is inherited from a European parent and is rare in Australian cultivars. This allele seems to delay flowering from an April sowing relative to Mace<sup>(1)</sup> quite successfully (Table 4).

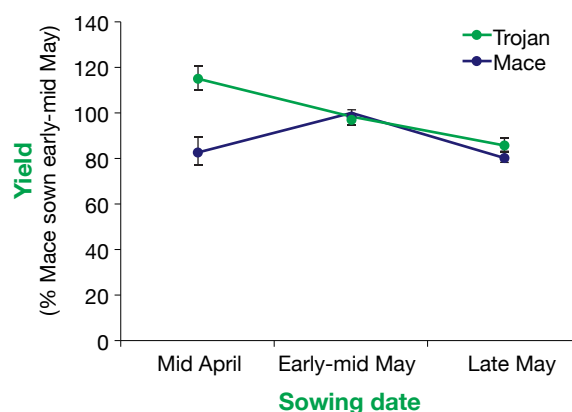


Figure 6: Mean yield performance (Minnipa, Cummins, Port Germein, Hart, Tarlee) of Trojan<sup>(1)</sup> and Mace<sup>(1)</sup> at different times of sowing relative to Mace<sup>(1)</sup> sown in its optimal window of early-mid May. Error bars are standard error of means.

Table 4: Flowering dates for Trojan<sup>(1)</sup> and Mace<sup>(1)</sup> from different times of sowing at Minnipa in 2014

Cultivar	Time of sowing		
	11 April	13 May	28 May
Trojan	6 August	10 September	17 September
Mace	8 July	6 September	13 September

Despite performing strongly from a mid-April sowing in these trials, Trojan<sup>(1)</sup> is not recommended for planting this early in most SA locations because it incurs excessive frost risk. As a guide, Trojan<sup>(1)</sup> is best suited to being planted ~10 days earlier than Mace<sup>(1)</sup>. As an example of how it may fit in a program, if 10 May is the optimal sowing time for Mace<sup>(1)</sup> in a given environment, then the optimal sowing time for Trojan<sup>(1)</sup> is 1 May. If a grower has a 20-day wheat-sowing program and wants to grow half Trojan<sup>(1)</sup> and half

Mace<sup>®</sup>, to maximise whole-farm yield, they should start with Trojan<sup>®</sup> on 25 April, switch to Mace<sup>®</sup> on 5 May and aim to finish on 15 May.

Sowing mid-April in low-frost environments such as Port Germein carries little risk, and as the year's results show, significant yield gains (0.9 t/ha relative to Mace<sup>®</sup>) can be achieved by sowing Trojan<sup>®</sup> in mid-April, because its longer growing season allows it to accumulate more dry matter.

For growers in frosty environments who wish to sow earlier than is safe with Trojan<sup>®</sup>–Mace<sup>®</sup>, EGA Wedgetail<sup>®</sup> is probably the best option. However, because of its poor adaption to SA even if sown in early–mid April, it is unlikely to yield as well as Mace<sup>®</sup> sown in its optimal window. In this set of trials, there was an average yield penalty of 0.5 t/ha between EGA Wedgetail<sup>®</sup> sown mid-April and Mace<sup>®</sup> sown mid-May. Grazing early-sown EGA Wedgetail<sup>®</sup> would offset some of the reduction in income compared with mid-May-sown Mace<sup>®</sup>.

Remember that early-sown crops require different management to achieve potential:

- Do not dry-sow slow-maturing varieties (EGA Wedgetail<sup>®</sup>, EGA Eaglehawk<sup>®</sup>). They will flower too late if not established early. Seedbed moisture is needed and ideally some stored soil water to get them through to winter.
- If growing winter wheat (EGA Wedgetail<sup>®</sup>) and not grazing, sow at lower plant density and defer N inputs until after Zadoks growth stage 30 (Z30 or GS30).
- Choose clean paddocks; winter wheat at low plant densities is not competitive with ryegrass, and common root diseases are exacerbated by early sowing.
- Protect against diseases associated with early sowing: *Barley yellow dwarf virus* (BYDV) (imidacloprid on seed, backed up with in-crop insecticides at the start of tillering if aphid is pressure high); *Septoria tritici* in some areas (flutriafol on fertiliser and timely foliar applications of epoxiconazole at Z30 and Z39). Many slow-maturing varieties also have poor resistance to stripe rust (flutriafol on fertiliser and timely foliar fungicide application at Z39)

### Conclusion

Despite July and August being frosty, highest yields in most trials came from mid-April sowing, with Trojan<sup>®</sup> being the standout performer. Trojan<sup>®</sup> complements Mace<sup>®</sup> in a cropping program and extends the sowing window to about 10 days earlier. EGA Wedgetail<sup>®</sup> was the best performing variety suited to a very early sowing, but even when sown early it yields less than Mace<sup>®</sup> planted in its optimal window.<sup>11</sup>

### 3.2.3 Variety and sowing-time options

Growers need to select wheat varieties to match their specific growing-season and agronomic requirements; selecting varieties with a spread of flowering dates can help to minimise risk if sowing starts early and spans at least a month. The later and shorter the sowing window, the less the difference that will occur in flowering time, even between varieties with different maturities (Figure 7).

Recommended sowing times for individual varieties and regions in Victoria and NSW are provided in state government department crop guides. Details of flowering dates are reported in the [SA Wheat variety sowing guide](#). The commercial program Yield Prophet<sup>®</sup> can assist with variety selection.<sup>12</sup>

<sup>11</sup> J Hunt *et al.* (2015) Sowing early in 2014—how did it work? GRDC Update Papers, 10 February 2015, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Sowing-early-in-2014--how-did-it-work>

<sup>12</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

### More information

[GRDC Update Papers: Sowing early in 2014—how did it work?](#)

[GRDC Update Papers: Early sowing in Victoria 2014](#)

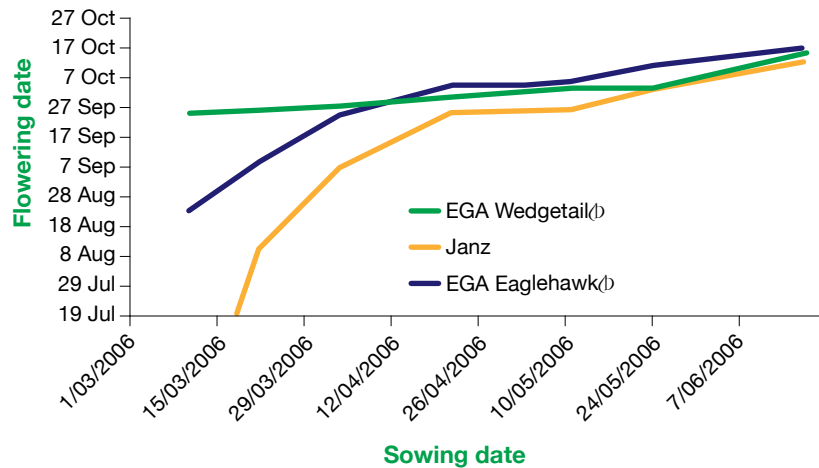


Figure 7: Flowering time as related to sowing date. Large differences in flowering time between varieties can be identified with very early sowing. In the southern region, when sowing from late April onwards, flowering dates become closer. EGA Wedgetail<sup>(1)</sup> is a winter variety and can be sown early because flowering is delayed until the strong cold requirement is met. By contrast, Janz has low vernalisation requirement, so very early sowing will cause very early flowering. EGA Eaglehawk<sup>(1)</sup> is intermediate for cold requirement.

Source: Peter Martin, NSW I&I

### Yield Prophet<sup>®</sup>

Yield Prophet<sup>®</sup> is an online decision-support tool for growers and advisers that can be accessed via a paid subscription. One part of the program can help with the process of selecting the best variety for a given sowing date or the best sowing date for a variety in the grower's own paddock (Figure 8).<sup>13</sup>

The model uses information about individual varietal responses to daylength and thermal time and cold requirements, in conjunction with information about the paddock and long-term climate data. More information is provided for some varieties and regions than for others; newer varieties and locations are supported by fewer data.

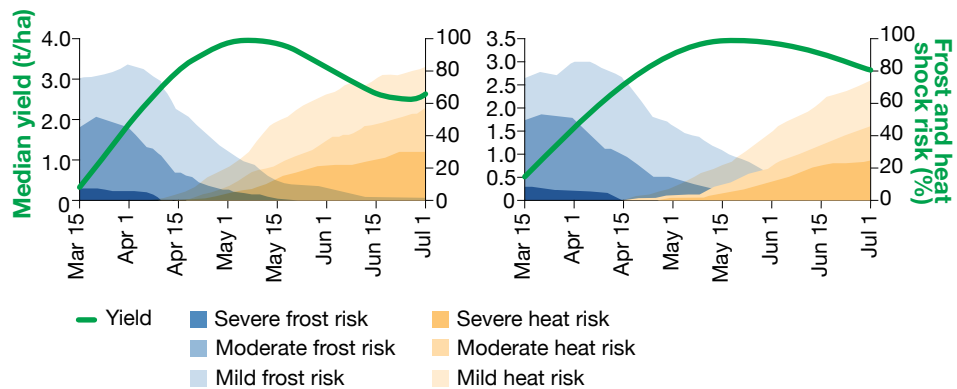


Figure 8: Example of a report from Yield Prophet<sup>®</sup>, showing that the optimal sowing time of the main-season variety Yitpi (left panel) is about 2 weeks before that of the early variety Young<sup>(1)</sup> (right panel) in a paddock at Culgoa, north-western Victoria. Although early-sown Yitpi has the highest potential yields, Young<sup>(1)</sup> is likely to yield 0.5 t/ha more if sowing is delayed until 15 June. Risk of frost and heat stress based on long-term climate data and relating to flowering and grainfill periods.

Source: Tim McClelland, BCG

<sup>13</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)



### 3.2.4 Balancing the risks

Early sowing within the recommended window for the variety generally maximises yields, with dry springs and no frosts favouring early flowering. Later sowings can require a different variety.

Given adequate rainfall and soil moisture, early sowing can set the potential for high yields. It aids fast establishment and good early growth due to warmer days.

Biomass contains carbohydrates, allowing grains to fill later in the season. Strong early growth provides more heads and a greater potential number of grains in each head.

Early sowing of an early-maturing variety with little or no vernalisation requirement and relatively insensitive to daylength (e.g. Axe<sup>(1)</sup>) will cause rapid development. The lack of biomass at flowering will reduce the number and size of heads and the number of grains. The lack of root depth will also limit the crop's ability to access moisture later in the season, leading to lower yields. Winter wheat varieties (e.g. EGA Wedgetail<sup>(1)</sup>) should be used for very early sowing opportunities.

Yield loss from delayed sowing within the window is not large, on average, but can be high in dry years. Modelling over 30 years showed that delaying sowing in the Victorian Mallee from 1 May to 1 June caused an average 2% yield loss. In two of these years, the yield loss was 0.5 t/ha. Similar results have been seen in trials across the southern region (Figure 9).

In seasons with a dry finish, early sowing (within the sowing window) has generally resulted in lower screenings and higher yields as crops mature during milder conditions. In those years, the benefit from early sowing in reducing moisture and heat stress has outweighed the effects of frost damage.

However, if high rates of N are applied upfront in early-sown crops, growth before flowering can be excessive. If moisture is limited during grainfill, the canopy will have limited capacity to fill all grains, leading to higher screenings and lower yields, even in the absence of frosts.<sup>14</sup>

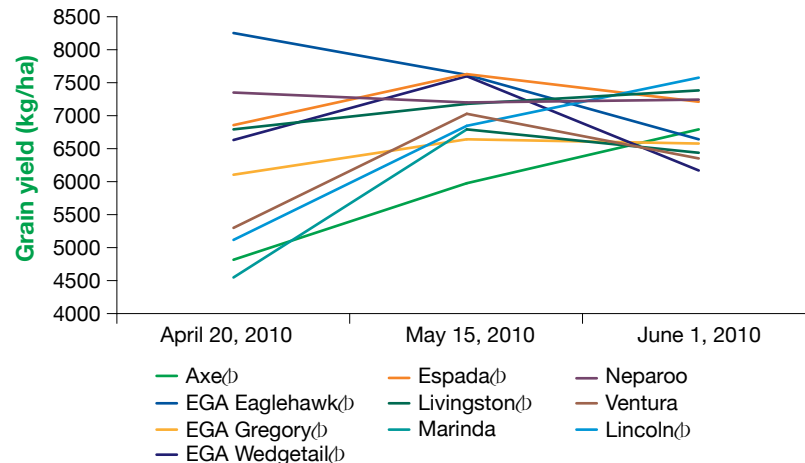


Figure 9: Example of variety response in yield to sowing time in a single trial at Cowra in 2010. Responses vary between trials (for more information visit NSW DPI Primefact: Yield response of wheat varieties to sowing time 2013).

Source: Jan Edwards, NSW I&I

#### Sowing time effect on diseases

Earlier sowing tends to increase the severity of yellow leaf spot and *Septoria tritici* blotch. *Wheat streak mosaic virus* (WSMV) and BYDV can also be worse with early sowing; however, for BYDV it depends on timing of the aphid flight. Warmer temperatures in early autumn favour wheat curl mite, which transmit WSMV.

<sup>14</sup> GRDC (2011) Impact on yield and quality of wheat. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

Delaying sowing is not a useful tool to aid stripe rust control because it is not consistently affected by sowing time. Early sowing can provide the benefit of the crop being more advanced when the disease arrives in a district. Conversely, early sowing can also increase levels of stripe rust at early crop stages, due to warmer temperatures in early autumn favouring rust cycling, and allow adult plant resistance to begin working at a later growth stage.<sup>15</sup>

Growers can identify the risk of significant soilborne and crown diseases with a PreDicta B soil test. Delayed sowing increases the severity of *Rhizoctonia*, cereal cyst nematode, *Pratylenchus* and crown rot. This is due to slower root growth with late sowing.

Delayed sowing can increase yield loss and screenings from crown rot, which is worsened by moisture and heat stress during grainfill. The effects are more severe in seasons with a hot and dry finish.

Take-all is less severe in later sown crops but only if weeds are controlled and inoculum has decomposed before sowing.<sup>16</sup>

### *Frost risk of early sowing*

The main risk of early sowing is frost between flowering and early grainfill. The optimal flowering window is based on long-term climatic data. However, frosts can still occur during the flowering window.

Winter wheats can be sown early where frost risk is a concern because their cold requirement delays flowering.

### *Managing frosts with sowing time*

Frosts can cause damage that reduces yield and can affect grain quality. Some varieties sown too early will flower in late winter. Varieties sown too late have little chance of reaching their yield potential because flowering and grainfill occur under hot, dry, stressful conditions.

Choice of sowing time is a management compromise between having the crop flowering soon after the last heavy frost, and allowing flowering sufficiently early for adequate grainfill before the onset of moisture stress and heat in spring.

If varieties are sown within the optimum sowing period, they can produce their highest yields, but the best sowing date varies with topography and variety. Sowing dates may need to be extended (earlier or later) depending upon local climatic conditions, paddock topography and soil types.

Although outlying severe frosts cannot be mitigated, the risk of seasonal frosts at flowering should be assessed and balanced. Frost damage (Figure 10) is a major consideration and the risk cannot be eliminated; therefore, the potential for higher yields from earlier sowings needs to be balanced against the risk of frost damage at flowering.

There are several ways of doing this:

1. Where the risk of frost is high (i.e. low-lying paddocks, regions with lower winter temperatures), sow later than the suggested optimum sowing period. As a rule of thumb, 3 days difference at planting makes 1 day of difference at heading.
2. Change varieties. Use maturity differences to have the crop flowering at a time when the seasonal frost risk is acceptable (Figure 11). Consider winter wheat, which can be grazed to delay maturity. If a significant frost event occurs, some income has already been achieved through grazing. Income can also be salvaged through cutting for hay.
3. Change crop type. Barley and oats are less susceptible to frost damage than wheat.

<sup>15</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

<sup>16</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

## Videos

[National frost initiative](#)

[Frost ratings](#)

[Frost susceptibility ranked](#)

4. Consider zoning the farm based on topography so that lower lying, high-risk areas can be managed separately. Some growers choose to sow these areas to pasture or implement rotations with a short cropping phase (grazing wheat and barley) followed by a long pasture phase.

Rain at sowing is often erratic; therefore, varieties must be chosen carefully to achieve this balance.<sup>17</sup>



Figure 10: Frosted wheat. (Photo: Rachel Bowman)

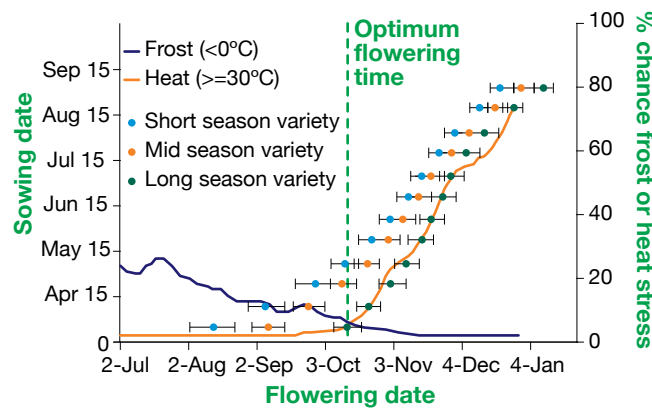


Figure 11: Relationship between variety maturity of wheat and sowing date to optimise time of flowering. The best sowing time results in flowering when the risks of frost, heat stress and dry conditions are lowest. In this example at Dunkeld, south-western Victoria, the optimal flowering time is, on average, 10 October. To achieve timely flowering, the winter variety needs to be sown early April, the midseason variety early May, and the early variety mid-May.

<sup>17</sup> P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide>

### 3.3 Controls on wheat development

The rate of development in wheat is controlled by vernalisation, temperature and daylength.

Development is different from growth, in that development refers to the crop moving between stages, whereas growth refers to an increase in biomass. In Australia, developmental stages are commonly referred to as 'growth stages'.<sup>18</sup>

#### 3.3.1 Vernalisation

To trigger flowering, winter wheat varieties need to experience low average temperatures of  $-3^{\circ}\text{C}$ – $17^{\circ}\text{C}$  above a base temperature (often assumed as  $0^{\circ}\text{C}$ ) after emergence. However, as temperatures become warmer within that range, the vernalisation rate is slower.

The minimum duration and temperature will depend on the variety. For this reason, winter varieties should not be sown in spring. Winter wheats vary in their need for cold temperatures. Most grower guides will state whether a variety is a winter wheat. Winter wheats are often dual-purpose varieties and, in Victoria and SA, are recommended only for high-rainfall regions with a long growing season, such as southern Victoria and the lower South-East of SA.

Most Australian wheat varieties are known as spring varieties. Spring wheats have little or no need for vernalisation, and the mild winter conditions in southern Australia's cropping areas are sufficient to meet the low vernalisation requirements of Australian spring wheats. The varieties H45<sup>Ⓢ</sup>, Axe<sup>Ⓢ</sup>, Janz, Young<sup>Ⓢ</sup> and Silverstar have only a very small vernalisation response.

Most spring wheats tolerate a shorter growing season than winter wheats.<sup>19</sup>

#### 3.3.2 Thermal time

Australian wheat crops will develop faster in warmer conditions provided the vernalisation requirement has been met. The accumulation of average daily temperatures largely dictates development for most Australian wheat varieties.

The time and temperature relationship governing growth and development is called 'thermal time' and is measured in 'growing degree-days'. This requirement differs between varieties. For barley, it is sometimes referred to as the 'basic vegetative phase'.

Thermal time is the average daily temperature, above a base temperature, multiplied by the number of days. Plants will stop developing if temperatures are below the base temperature. The base temperature is often assumed as  $0^{\circ}\text{C}$  for calculations, although it actually differs between varieties. For the calculation to proceed, the average daily temperature needs to be above the base temperature for the crop.

For spring wheats, thermal time is the main driver of development (Figure 12). It usually takes 150 degree-days from sowing for wheat to emerge. When average daily temperature is  $10^{\circ}\text{C}$ , emergence will take 15 days (i.e.  $10^{\circ}\text{C} \times 15 \text{ days} = 150 \text{ degree-days}$ ). If the average daily temperature is  $15^{\circ}\text{C}$ , emergence will take only 10 days.<sup>20</sup>

<sup>18</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

<sup>19</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

<sup>20</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)



Figure 12: For spring wheats, thermal time is the main driver of development. (Photo: Emma Leonard)

### 3.3.3 Daylength

For some Australian wheat varieties, mainly grown in northern Australia, daylength (photoperiod) can also affect the length of time required to reach growth stages. Genetic studies and observations of wheat varieties grown at different latitudes suggest that many Australian wheat varieties are daylength-sensitive (to varying degrees). However, most varieties are not well characterised for responses to daylength.

The closer to the equator, the less is the variation in daylength. Daylength increases after 22 June. The longer the days, the shorter the thermal time needed to initiate flowering in photoperiod-sensitive wheat varieties.

Varieties released before 1973 generally carried a photoperiod-sensitive gene, making them more sensitive to daylength. They tended to flower later for a given sowing date when sown before 22 June—on average 1 week later in the Mallee—than current varieties. A photoperiod-sensitive variety will flower 4–12 days later than a photoperiod-insensitive variety when sown early in southern Australia, depending on its need for vernalisation.<sup>21</sup>

## 3.4 Targeted plant population

Plant population, determined by seeding rate and establishment percentage, can be an important determinant of tiller density and, at a later stage, head density.<sup>22</sup>

High yields are possible from a wide range of plant populations. This is because wheat compensates by changing the number of tillers and the size of the heads in response to the environmental conditions, including weather, fertility and plant competition (Figure 13). Varieties differ in their ability to do this; for example, Spitfire<sup>®</sup> produces low tiller numbers, whereas Sunvale<sup>®</sup> produces very high tiller numbers (Figure 14).

Despite the ability to compensate, targeting a variety's optimum plant density at sowing makes the most efficient use of water and nutrients. To reach a target plant population

<sup>21</sup> GRDC (2011) Impact on yield and quality of wheat. Southern Region. Time of Sowing Fact Sheet, GRDC, 3 March 2011, [http://www.grdc.com.au/uploads/documents/grdc\\_fs\\_timeofsowing\\_south.pdf](http://www.grdc.com.au/uploads/documents/grdc_fs_timeofsowing_south.pdf)

<sup>22</sup> G Butler, W Manning, L Serafin (2003) Population density studies in sorghum and wheat. GRDC Update Papers, 19 Sept. 2003, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2003/09/Population-density-studies-in-sorghum-and-wheat>

for the environment and seasonal conditions, adjust sowing rates to allow for:

- sowing date—higher rates with later sowings
- seed germination percentage
- seed size
- seedbed conditions
- tillage, e.g. no-till
- double-cropping
- soil fertility
- soil type
- soil moisture and seasonal outlook
- weed seed burden—higher sow rates for increased plant competition, e.g. if combatting herbicide-resistant ryegrass populations <sup>23</sup>



Figure 13: Trials showed that high plant populations do not necessarily lead to small grain or high screenings.



Figure 14: Sunvale wheat is an example of a variety with the ability to produce a high number of tillers. (Photo: Susan McDonnell)

<sup>23</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

In 2000, TOPCROP Victoria investigated sowing rates for wheat to achieve target plant densities by using large-scale paddock demonstrations. TOPCROP farmer groups established 30 sites across Victoria comparing 75%, 100%, 150% and 200% of the district practice for sowing rate, using Silverstar and a farmer-selected wheat variety. Initial findings indicated that poor seeder calibration and a lack of understanding of the influence of grain size have led to target plant densities not being reached. This highlights the need for sowing recommendations to be based on target plant densities rather than sowing rates.<sup>24</sup>

### FAQ 3.4.1 Calculating a seeding rate

Because seed sizes may vary depending on production years and variety type, a fixed quote for the weight of seed needed to sow 1 ha is not always an accurate measure for obtaining a desired plant population per hectare. Average graded seed sizes are:

- large, 24,000 seeds/kg
- medium, 27,500 seeds/kg
- small, 30,000 seeds/kg

An actual seed count is required to calculate a more accurate sowing rate. A formula based on 1000-seed weight can be used. To determine 1000-seed weight, count out 200 seeds, weigh to within 0.1 g and multiply by 5. Then calculate the sowing rate:

$$\text{Sowing rate} = \frac{(\text{target density} \times 1000\text{-seed weight}/100)}{(\text{establishment percentage} \times \text{germination percentage})}$$

Germination percentage can be found on bag labels, or you can do your own germination tests and/or seed counts.<sup>25</sup>

### 3.4.2 Plant spacing

#### *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. In many instances, this has

<sup>24</sup> A Johnson, M Evans, K Wansink (2001) Challenging sowing rates for wheat to achieve target plant densities. 10th Australian Agronomy Conference, Australian Society of Agronomy/The Regional Institute Ltd, <http://www.regional.org.au/au/asa/2001/p/10/johnson.htm>

<sup>25</sup> DAF Qld (2012) Wheat—planting information. Department of Agriculture and Fisheries, Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/planting-information>

doubled the initial emergence. Gypsum application may help alleviate this problem on hard-setting clays.<sup>26</sup>

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.

Poor-quality seed with low laboratory germination will give poor establishment; for example, weathered seed that has been stored under high temperature and humidity, or seed that has been attacked by insects.

### *How to measure your plant population*

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

## **i** More information

[GRDC: Crop placement and row spacing – Southern Fact Sheet](#)

### 3.4.3 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.

The traditional row spacing in much of southern Australia has been 15–20 cm. Greater adoption of no-till farming systems has increased interest in wider row spacing, such as 30–50 cm, depending on the crop type and region.

Until recently, the trend was to widen row spacing to accommodate stubble retention practices. Recent evidence shows that widening row spacing decreases yields, particularly in areas of higher yield potential. Growers in these areas are returning to narrower row spacing for yield and weed-control benefits (crop competition). Improvements to disc or tine/knife-point seeding systems means that stubble handling at narrow row spacing has also improved, although tine systems usually require some form of stubble management such as mulching after harvest.

Row spacing is a compromise between:

- ease of stubble handling
- optimising seedbed utilisation and travel speed
- managing weed competition and soil throw
- 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.

The 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.

<sup>26</sup> 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>



### Effect on yield

The higher the yield potential, the greater the negative impact of wide rows on cereal yields.<sup>27</sup> The impact of row spacing on yield varies depending on the growing-season rainfall.

Analysis of data from the NSW DPI VSAP project, covering a large number of row-space experiments in wheat, canola and lupins, revealed that widening the row space of wheat decreased yields when yields were above ~1.3 t/ha (Table 5). However, at yields <1.3 t/ha there was a small increase in grain yield.

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). Some 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 (Figure 15).<sup>28</sup> 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 the Southern Farming Systems near Geelong, Victoria, have shown that row spacing of 40 cm reduced wheat yield by ~6% compared with row spacing of 20 cm.

The value of these yield reductions should be taken into account when considering farming system options that use equipment with wider row spacing. The likely economic loss from row-space widening should be offset by the economic advantages of the minimum-till stubble-retention system. At low yield, it is easy to justify the decision to widen row space.

However, at higher yield levels, the loss of yield with widening of rows increases, and the offset benefits of stubble-retention system need to be carefully evaluated. If benefits are not sufficient to make up for the loss associated with wide rows, then alternative methods for retaining stubble, including sowing into stubble using narrower row spacing, should be investigated.<sup>29</sup>

Table 5: Yield (t/ha) and economic cost or benefit (\$/ha) of using wide sowing with wheat and canola in central and southern NSW (wheat at \$250/t and canola at \$500/t)

Row spacing – wheat			Row spacing – canola		
18cm	30cm	42cm	18cm	30cm	42cm
1.00	1.03 (+\$6)	1.05 (+\$13)	1.00	0.95 (-\$25)	0.90 (-\$50)
2.00	1.95 (-\$12)	1.90 (-\$24)	2.00	1.91 (-\$47)	1.81 (-\$97)
4.00	3.81 (-\$48)	3.61 (-\$97)	3.00	2.86 (-\$71)	2.71 (-\$144)
6.00	5.66 (-\$85)	5.32 (-\$170)	4.00	3.81 (-\$94)	3.62 (-\$191)

<sup>27</sup> GRDC (2011) A systems approach to row spacing. Southern Region. Crop Placement and Row Spacing Fact Sheet, GRDC, January 2011, [http://www.grdc.com.au/uploads/documents/GRDC\\_FS\\_CropPlacement\\_South.pdf](http://www.grdc.com.au/uploads/documents/GRDC_FS_CropPlacement_South.pdf)

<sup>28</sup> BJ Scott, P Martin, GP Riethmuller (2013) Row spacing of winter crops in broad scale agriculture in southern Australia. Graham Centre Monograph No. 3, Graham Centre for Agricultural Innovation, [http://www.csu.edu.au/\\_data/assets/pdf\\_file/0010/922465/2013-Row-spacing-of-winter-crops-in-broad-acre-agriculture-in-southern-Australia.pdf](http://www.csu.edu.au/_data/assets/pdf_file/0010/922465/2013-Row-spacing-of-winter-crops-in-broad-acre-agriculture-in-southern-Australia.pdf)

<sup>29</sup> NSW DPI (2012) Wide row spacing reduces wheat and canola yields. *Agriculture Today* May 2012, NSW Department of Primary Industries, <http://www.dpi.nsw.gov.au/archive/agriculture-today-stories/ag-today-archive/may-2012/wide-row-spacing-reduces-wheat-and-canola-yields>



Figure 15: Generally, increasing row spacing up to 30 cm has no effect on wheat yield where yield potential is <3.5 t/ha. (Photo: Emma Leonard)

### Soil moisture

Closer row spacing can reduce evaporation by increasing the rate of canopy closure. Wider row spacing can increase evaporation from the soil between the rows, but this can be offset by inter-row stubble mulching and the interception and concentration of rainfall into the crop row.

Field experiments in SA during 2006 investigated the water- and radiation-use efficiency of wheat, barley and faba beans grown on conventional spacing (18 cm) and wide row spacing of 36 and 54 cm.

The trial was conducted during a dry season with growing-season rainfall 181 mm (median 300 mm) and found clear differences in yield responses for the crops grown at different spacings. The yield trends for wheat and barley were similar.

Doubling the row spacing from 18 to 36 cm resulted in a 2% loss in yield in barley and a 5% loss in wheat. When row spacing was extended to 54 cm, a yield reduction of up to 24% was recorded in both cereals.<sup>30</sup>

### Weed competition

At Merredin, Western Australia, in a 27-year trial run by Glen Riethmuller from Department of Agriculture and Food WA, narrow row spacing (18 cm) with normal

<sup>30</sup> GRDC (2011) A systems approach to row spacing Southern Region. Crop Placement and Row Spacing Fact Sheet, GRDC, January 2011, [http://www.grdc.com.au/uploads/documents/GRDC\\_FS\\_CropPlacement\\_South.pdf](http://www.grdc.com.au/uploads/documents/GRDC_FS_CropPlacement_South.pdf)

herbicide use and full stubble retention greatly reduced ryegrass numbers compared with the 36-cm row spacing (0.17 v. 7.67 seed heads/m<sup>2</sup>).<sup>31</sup>

Increasing row spacing can create weed problems. Wider spacing reduces the crop's ability to close the canopy and compete with weeds between rows. At row spacing >40 cm, canopy closure in cereals may never occur. This makes weed control extremely important.

Wider row spacing can allow weeds to be controlled by using higher rates of incorporated-by-sowing (IBS) herbicides.

Trifluralin and pendimethalin can be applied as a 'hot blanket' of herbicide and incorporated between the crop rows by using a seeding bar fitted with tines, not discs.

Trials by the Birchip Cropping Group in the Victorian Mallee found that reduced plant establishment could occur when relatively high rates of pre-emergent herbicide were used with narrower row spacing (<22.5 cm). Slightly higher seeding rates can be used to compensate for these reductions. The risk of crop damage from pre-emergent herbicides is greatly reduced when used with wide row spacing.<sup>32</sup>

### Equipment

Most growers in the Southern Region use either a knife-point/press-wheel tine system or a single disc. Disc seeders can handle greater quantities of stubble but experience crop damage issues with pre-emergent herbicide use. Tine seeding systems do not have the same herbicide safety issues but usually require some form of post-harvest stubble treatment, such as mulching or burning.<sup>33</sup>

### Inter-row cropping

In combination with GPS guidance that provides at least ±10 cm accuracy, wide row spacing allows subsequent crops to be located on the inter-row. Inter-row systems can improve stubble flow; however, it is important that tines do not catch the stubble row because this can cause establishment problems. When using RTK guidance that provides ±2 cm accuracy, the best results are achieved when the minimum wide-row spacing is ~25 cm.

### Fertiliser

Fertiliser rates may need to be refined for wide row spacing. Wider row spacing can lead to an increased concentration of fertiliser in rows or a reduced fertiliser rate per hectare at seeding. Consequently, changes in the amount of fertiliser applied at seeding and during the growing season may be required with wider row spacing. Increased fertiliser requirements can occur when there is incomplete exploration of the surface soil by plant roots, such as in dry years.

Banding fertiliser below the seed will help to minimise the effects of fertiliser toxicity. This can occur if seeding fertiliser rates are maintained but row spacing is increased. Soil fertility can also vary between the row and inter-row space in wide-row cropping systems. There may be residual phosphorus in the soil following a dry year. Nitrogen fixation following pulses or nutrient tie-up by stubble may affect soil fertility. This can influence the fertiliser required for the following crop.

To establish soil nutrient status in systems using wider row spacing, a modified approach to soil sampling is suggested. Take equal numbers of soil samples from the row and inter-row for an average fertility content of the paddock. If planning to precision-sow (either row or inter-row), there may be value in having the row and

<sup>31</sup> WeedSmart. Narrow row spacing: is it worth going back? WeedSmart, <http://www.weedsmart.org.au/bulletin-board/narrow-row-spacing/>

<sup>32</sup> GRDC (2011) A systems approach to row spacing Southern Region. Crop Placement and Row Spacing Fact Sheet, GRDC, January 2011, [http://www.grdc.com.au/uploads/documents/GRDC\\_FS\\_CropPlacement\\_South.pdf](http://www.grdc.com.au/uploads/documents/GRDC_FS_CropPlacement_South.pdf)

<sup>33</sup> K Condon (2014) Disc seeding in southern NSW. Grass Roots Agronomy, <http://www.grassrootsag.com.au/assets/disc-lr.pdf>

inter-row samples tested separately. This will allow any variation in soil fertility to be exploited. Sowing into an area of high residual phosphorus or nitrogen may reduce starter fertiliser requirements, and sowing away from residual fertility will delay crop access.<sup>34</sup>

### 3.5 Sowing depth

Factors that influence a seedling's ability to emerge from depth include:

- seed size
- seed treatments
- coleoptile length (this varies with variety)
- herbicides
- soil conditions including temperature

In seasons with a dry start, deep sowing into moisture can ensure that crops are established in their optimal sowing window. The deeper sowing may reduce crop germination, but the yield from the earlier sowing may offset yield losses associated with delaying sowing to later in the season.

Deep sowing is only an option in soils that store soil moisture and can be cultivated to depth. Care should be taken to avoid bringing sodic clays into the topsoil, which can increase dispersion, hard-setting and salinity. Some fungicidal seed treatments reduce coleoptile length in cereals and treated seeds should be shown at shallower depths.

A uniform seeding depth is achieved with press-wheels, which minimise the variation in soil cover provided they produce a regular, stable furrow.

Optimum planting depth varies with planting moisture, soil type, seasonal conditions, climatic conditions, and the rate at which the seedbed dries. The general rule is to plant as shallow as possible, provided the seed is placed in the moisture zone, but deep enough that the drying front will not reach the seedling roots before leaf emergence and that the seed is separated from any pre-emergent herbicides used.<sup>35</sup>

Optimum planting depth for wheat is 30–35 mm for semi-dwarf varieties through to 50–70 mm for tall wheat varieties, which have a longer coleoptile. Coleoptile length will be reduced with warm seedbed conditions and with the addition of some seed dressings.

Planting depth will therefore be more critical with early planting (e.g. April and early May), and varieties with short coleoptiles should be avoided at this time.

In trials, although deeper sowing (10–15 cm) reduced establishment rate, the gains from maximising yield potential by sowing at the optimal time tended to compensate for the lower plant population. Thus, it was better to sow deeper and on time and chance a lower plant population than to wait for another rainfall event and plant outside the optimal window.<sup>36</sup>

Sowing depth influences the rate of emergence and the percentage emergence. Deeper seed placement slows emergence; this is equivalent to sowing later. Seedlings emerging from greater depth are also weaker and more prone to seedling diseases, and may tiller poorly.

Crop emergence is reduced with deeper sowing because the coleoptile may stop growing before it reaches the soil surface, with the first leaf emerging from the coleoptile

<sup>34</sup> GRDC (2011) A systems approach to row spacing Southern Region. Crop Placement and Row Spacing Fact Sheet, GRDC, January 2011, [http://www.grdc.com.au/uploads/documents/GRDC\\_FS\\_CropPlacement\\_South.pdf](http://www.grdc.com.au/uploads/documents/GRDC_FS_CropPlacement_South.pdf)

<sup>35</sup> 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/Proccrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Proccrop-wheat-growth-and-development.pdf)

<sup>36</sup> 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/Proccrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Proccrop-wheat-growth-and-development.pdf)

while it is still below the soil surface. Because it is not adapted to pushing through soil (does not know which way is up), the leaf usually buckles and crumples, failing to emerge and eventually dying.<sup>37</sup>

For more information on the effect of coleoptile length, see [GrowNotes Wheat South Section 2. Pre-planting](#).

### 3.5.1 Deep planting

In some seasons, moisture seeking or deep sowing is a tool that growers can use to ensure that crops are established in their optimal window.

Some of the potential disadvantages of deep sowing are delayed emergence, poor establishment, reduced early vigour, increased disease susceptibility and reduced grain yield. Research trials are investigating wheat and durum varietal responses to seeding depth and the impact of triadimenol on emergence.<sup>38</sup>

Deep sowing may delay or stifle emergence, whereas shallow sowing risks seed damage from herbicide uptake. The length of the first shoot (coleoptile) has a bearing on depth of sowing. If a variety is sown deeper than the natural growth extension of the coleoptile then the seedling may not emerge. Most current varieties are derived from so-called semi-dwarf lines, which have shorter stems and shorter coleoptiles than older varieties.

Seasonal differences in depth and availability of moisture influence decisions about depth of sowing. A sowing depth 25–50 mm, depending on soil type and available moisture, is a useful guide for seed placement. In moist conditions, shallower sowing may encourage faster emergence and crop establishment.<sup>39</sup>

The main benefits from deep sowing are gained by establishing varieties in the optimal sowing window. When considering deep sowing or moisture seeking, use seed of large size and high germinative capacity. Also, consider increasing seeding rates to compensate for the reduced emergence of deep sown crops.<sup>40</sup>

Trials during 2009–11 at Coonamble, NSW, showed that deep sowing could have a significant effect on the establishment and yield of wheat; however, none of the varieties evaluated showed an enhanced ability to establish from deep sowing compared with other, commonly grown varieties in the region. Producers need to make several decisions when considering moisture seeking; however, there appears no resultant advantage in crop establishment from changing varieties.<sup>41</sup>

It was unclear whether the reduced yield from deep sowing in 2009 was due to a reduced plant population or to subsequent effects on crop growth and development. Other trials at the same site and in the same season reported no significant difference in wheat yield from plant populations in the range 60–180 plants/m<sup>2</sup>. However, the lower plant populations in that work were still higher than the populations achieved in the deep-sowing treatments of the sowing-depth trial.<sup>42</sup> Hence, there was likely some yield

<sup>37</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

<sup>38</sup> G McMullen, R Brill, N Fettell (2011) Row spacing and deep sowing. GRDC Update Papers, 18 April 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/04/Row-spacing-and-deep-sowing>

<sup>39</sup> Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

<sup>40</sup> G McMullen, R Brill, N Fettell (2011) Row spacing and deep sowing. GRDC Update Papers, 18 April 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/04/Row-spacing-and-deep-sowing>

<sup>41</sup> R Brill, G McMullen, M Gardner (2012) The effect of sowing depth on the establishment of several commercial wheat varieties. 16th Australian Agronomy Conference. Australian Society of Agronomy/The Regional Institute Ltd, [http://www.regional.org.au/au/asa/2012/crop-production/8196\\_brillr.htm#TopOfPage](http://www.regional.org.au/au/asa/2012/crop-production/8196_brillr.htm#TopOfPage)

<sup>42</sup> G McMullen, R Brill, N Fettell (2011) Row spacing and deep sowing. GRDC Update Papers, 18 April 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/04/Row-spacing-and-deep-sowing>

effect due to reduced population. Deep sowing reduces tillering and subsequent head number per plant and per unit area, which might also have reduced yield in the sowing-depth trial.

The 2011 trial highlighted the potential benefits of moisture seeking; in that season, reduced establishment from a relatively early, deep sowing resulted in higher yield than a shallow, late sowing that achieved a higher plant population. In this trial, the adverse effect of delayed sowing on wheat yield was greater than that of deep sowing. Where producers and agronomists are faced with situations of low seedbed moisture but high plant-available water beyond the seedbed (>5 cm soil depth), planting decisions need to balance the potential effect of reduced yield from deep sowing with the potential yield loss from delayed sowing.<sup>43</sup>

### 3.5.2 Depth control

Some compromises to planting machines to minimise depth variation:

- Frame length and width affects seed depth. Flexible frames with sectional widths <3 m will assist, as will large-diameter, tandem walking wheels.
- Planter units fitted behind tillage implements give good depth control. Depth control wheels should be as close as possible to the line of planting tines. Select planting tines on bars towards the centre of the planter rather than on the front or rear bar.
- To overcome the problem of high breakout tines driving too deeply into small hills in the seedbed, some form of scraper on the tine may be useful. Flat chisel tines have some advantage in displacing surplus soil.
- In controlled traffic situations where crossing contour banks is necessary, ground-following tools such as pivoting tines or parallelograms will give much better depth control and may justify the additional cost over fixed tines.
- Press-wheels will often compensate for poor depth control.<sup>44</sup>

## 3.6 Germination testing

For information on quality of planting seed, see [GrowNotes Wheat South Section 2. Pre-planting](#).

## 3.7 Planting techniques

The benefits of conservation farming are increased fallow stored moisture, less soil erosion, opportunity cropping and lower tillage costs. Even with no-tillage or reduced-tillage planting, a seedbed is required in the zone where the seed is to be placed.

Typical 'planting techniques' now involve stubble retained or no-till systems based on managing soil structure and soil moisture levels through strict fallow management and, increasingly, controlled traffic systems.

### 3.7.1 Inter-row sowing

Inter-row sowing has been shown to reduce the impact of crown rot and increase yield by up to 9% in a wheat-wheat sequence. Crop rotation reduces the incidence and severity of crown rot, resulting in yield gains of 17–23% over continuous wheat. Research reported in 2013 examined whether row-placement strategies coupled with a break crop-wheat rotation would result in differences in grain yield over a 5-year crop sequence.<sup>45</sup>

<sup>43</sup> R Brill, G McMullen, M Gardner (2012) The effect of sowing depth on the establishment of several commercial wheat varieties. 16th Australian Agronomy Conference. Australian Society of Agronomy/The Regional Institute Ltd, [http://www.regional.org.au/au/asa/2012/crop-production/8196\\_brillr.htm#TopOfPage](http://www.regional.org.au/au/asa/2012/crop-production/8196_brillr.htm#TopOfPage)

<sup>44</sup> DAF Qld (2012) Wheat—planting information. Department of Agriculture and Fisheries, Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/planting-information>

<sup>45</sup> A Verrell (2013) *Row placement strategies in a break crop wheat sequence*. GRDC Update Papers, 26 Feb. 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Row-placement-strategies-in-a-break-crop-wheat-sequence>

## More information

[GRDC Ground Cover: Helping hand on inter row sowing for SA growers](#)

[GRDC Update Paper: Row placement strategies in a break crop wheat sequence](#)

[GRDC Research & Development: On-row versus inter-row sowing](#)

[GRDC Update Papers: Reduce losses from crown rot through variety choice and inter-row sowing](#)

## Video

[SFS Seeder Trial](#)

Following a wheat crop, the break crop (pulse or oilseed) should be sown between the standing stubble rows. In the next year, the wheat crop should be sown directly over the previous season's break-crop row. Then in the next year of the rotation, the break crop should be sown between the standing wheat rows. Finally, in the fifth year, the wheat crop should again be sown directly over the previous year's break-crop row.

There are two simple rules to follow:

- Sow break crops between standing wheat rows, which need to be kept intact.
- Sow the following wheat crop directly over the row of the previous year's break crop.

By adopting these rules, you ensure the following:

- 4 years between wheat crops being sown in the same row space
- a substantially reduced incidence of crown rot in wheat crops
- improved germination of break crops, especially canola, not hindered by stubble
- benefit to chickpeas from standing stubble reducing the impact of virus
- standing wheat stubble providing better protection to break-crop seedlings<sup>46</sup>

## 3.8 Sowing equipment

As much as 60% of the final yield potential for a wheat crop is determined at planting. Seeding too thinly, using poor-quality seed, and uneven stands result in end-of-season yield losses that cannot usually be overcome.<sup>47</sup>

During the shift from conventional to no-till farming systems, the effective use of herbicides has become increasingly important. To remain effective, herbicide strategies are being used in conjunction with other measures including crop competition, harvest weed seed control, brown manure and strategic hay cutting.

Over the last 5–6 years, 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 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 have different label claims for the same active ingredient. This creates problems for farmers and agronomists wanting to use these herbicides in modern, no-till farming systems.

Residual herbicides at sowing are very effective for controlling a wide range of weeds both in-crop and 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 paramount to enable 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, while others are less so. Mobility can also change with time for particular herbicides. For example, the longer that Boxer Gold<sup>®</sup> (a.i.s prosulfocarb, S-metolachlor) 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<sup>®</sup> (a.i. triasulfuron) are mobile regardless of binding period.

<sup>46</sup> A Verrell (2013) *Row placement strategies in a break crop wheat sequence*. GRDC Update Papers, 26 Feb. 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Row-placement-strategies-in-a-break-crop-wheat-sequence>

<sup>47</sup> W Thomason (2004) Planting wheat: seeding rates and calibration. Virginia Cooperative Extension, <http://www.sites.ext.vt.edu/newsletter-archive/cses/2004-10/plantingwheat.html>

The 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 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 occur 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-emergence (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, with 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. It is important to 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 press-wheels all have an impact on 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 IBS rather than PSPE application of herbicides.

Knife-points and harrows cause a lot of herbicide-treated soil to return into the seed furrow and are, therefore, not ideally used in IBS application. Knife-points and press-wheels do a much better job.<sup>48</sup>

Seeder calibration is important for precise seed placement and seeders should be checked regularly during sowing (Figure 16).

<sup>48</sup> B Haskins (2010) Residual herbicides at sowing using disc and tyne no till seeding equipment. NSW. Riverine Plains, [http://riverineplains.com.au/literature/53801/Residual\\_Herbicides\\_-\\_Barry\\_Haskins](http://riverineplains.com.au/literature/53801/Residual_Herbicides_-_Barry_Haskins)





Figure 16: Seeder calibration is important for precise seed placement and seeders need to be checked regularly during sowing. (Photo: Rohan Rainbow)

## FAQ

### 3.8.1 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.

Each seeder will create a different environment for an establishing crop, and it is essential to understand this before use of pre-emergent herbicides.

Knowledge of how this environment may change with IBS or PSPE incorporation methods is also necessary. In general, much difference in crop safety is achieved between seeders in IBS systems, and less difference between 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 typically being the preferred method in conservation farming systems.

The sowing process is relied upon to ensure that the pre-emergent herbicide is incorporated effectively and that the seed is placed into a micro-environment that allows safe and effective germination. In all cases, it is ideal to use a knife-point or disc followed by a press-wheel. Press-wheels are essential to provide the seed with good soil contact and to 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. It is important to understand that all seeding gear is different, which, in turn, creates varying seedbed conditions.

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

To ensure adequate soil throw, some users assume 1 km/h for every 1 cm of row spacing. This is not correct, and there is no rule for soil throw, row spacing and sowing speed because of the variability discussed previously. The only way to check for adequate soil throw is to check every situation.

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

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

This research has also shown that some herbicides and rates of particular herbicides are better suited to a disc seeder system than are others (Figure 17). This is usually correlated with how a seedling metabolises a particular herbicide if contact is made. From Figure 17, trifluralin at higher rates is definitely not suited to disc seeding systems, because crop vigour may be adversely affected.<sup>49</sup>

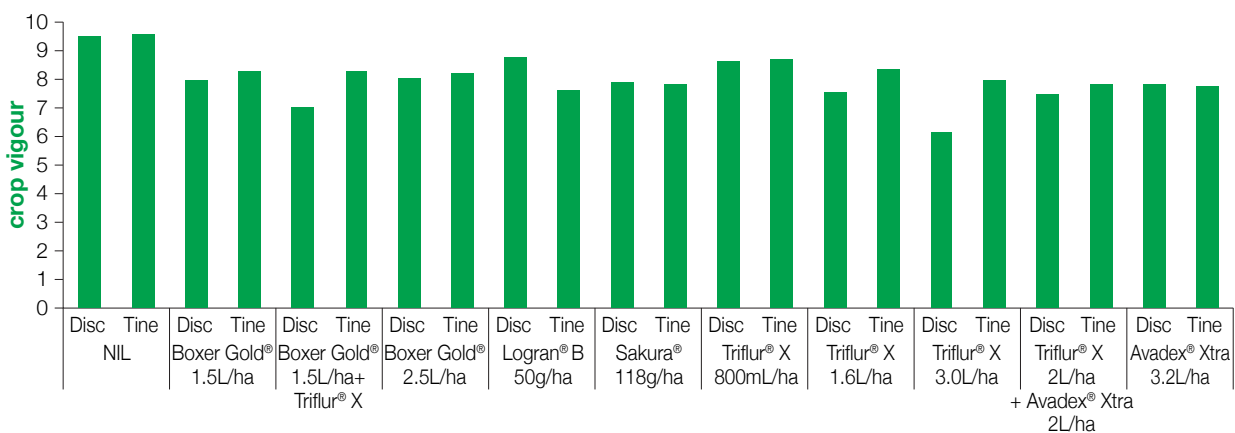


Figure 17: Difference in crop safety between discs and tines across commonly used pre-emergent herbicides in trials in southern and central NSW. Various disc and tine seeders were used for these trials. 0, No crop vigour; 10, vigorous crop.

<sup>49</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf)

## SECTION 4

# Plant growth and physiology

## More information

[GRDC Update Papers: Cereal growth stages and decision making for fungicide timing](#)

[GRDC: Zadoks Growth Scale](#)

Knowing the growth stages of cereals is critical for management practices. 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 nitrogen, plant growth regulators, fungicides and water.

Zadoks Cereal Growth Stage Key is the most commonly used growth stage key for cereals. The development of the cereal plant is divided into 10 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.<sup>1</sup>

## 4.1 Germination and emergence

### 4.1.1 Germination

Wheat 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 heading 4. Plant growth stages, for detail on Zadoks Cereal Growth Stage Key)

Phase 1 starts when the seed begins to absorb moisture. Generally, a wheat 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.

Wheat 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 absorb and begin Phase 1, but it takes longer than in moist 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. The larger the seed, the more starch and therefore energy it will have. 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–GS09)*

In Phase 3, the embryo starts to grow visibly. The radicle emerges, followed soon after by other primary roots and the coleoptile. The enzymes produced in Phase 2 mobilise

<sup>1</sup> N Poole (2005) Cereal growth stages. GRDC, <http://www.grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf>

sugars and amino acids stored in the seed and enable their transfer to the growing embryo.<sup>2</sup>

### Storage on-farm

Seed that is dry, cool and not weather-damaged will remain viable for longer. In well-managed storage, germination can be expected to reduce by only 5% after 6 months. To achieve this, grain moisture content should be kept below 12%.

Grain temperature also has a major impact on germination. Aim for grain temperatures of  $\leq 20^{\circ}\text{C}$  in seed storage by using aeration cooling (with auto control). Wheat at 12% moisture content stored at  $30^{\circ}\text{--}35^{\circ}\text{C}$  (unaerated grain temperature) will have reduced germination percentages and seedling vigour when stored over a long period. Small seed silos should be positioned in the shade or painted reflective white to assist in keeping grain cool.<sup>3</sup> (See [GrowNotes Wheat South Section 13. Storage.](#))

### 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.

The coleoptile (Figure 1) is well developed in the embryo, forming a thimble-shaped structure covering the seedling tube 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 about 50 mm long and 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, and 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.<sup>4</sup> The difference between the coleoptile and the first true leaf is that the coleoptile knows which way the soil surface is. If it does not reach the surface, the first leaf may emerge under the soil and grow in any direction.

<sup>2</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

<sup>3</sup> P Burrill, P Botta, C Newman, B White, C Warrick (2014) Northern and southern regions—Grain storage pest control guide. Grain Storage Fact Sheet, GRDC, revised July 2014, <http://storedgrain.com.au/northern-southern-regions-grain-storage-pest-control-guide/>

<sup>4</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

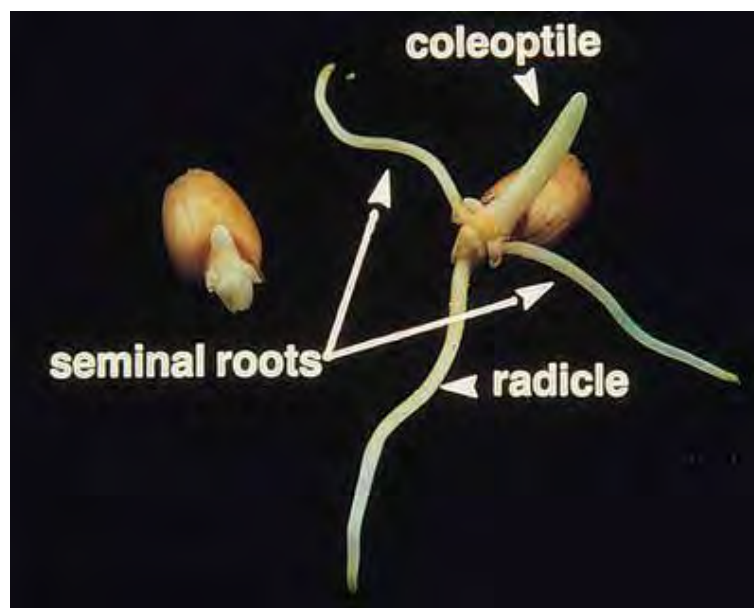


Figure 1: Germinated wheat seed. (Source: University of Minnesota)

## 4.2 Factors affecting germination and emergence

### 4.2.1 Dormancy

In a wheat seed, germination begins after a very short period of dormancy. Australian wheats have a low level of dormancy that is easily broken down, allowing germination to begin. By contrast, European and North American red wheat varieties have a dormancy derived from their seed coat that lasts 3–7 months. This dormancy is linked to anthocyanins, the enzymes that give the seed coat the red colour.

In Australian white wheats, at least two genes influence the level of dormancy. One gene is expressed in the embryo of the seed and must be present for any level of seed dormancy to develop. This gene makes the grain sensitive to the plant hormone abscisic acid, which prevents germination at the time of 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. This level of dormancy is essential in varieties targeted for Queensland and northern New South Wales because of summer rainfall, and is highly desirable in southern Australia.<sup>5</sup>

### 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. Instead of 5 days at 7°C when there is adequate moisture, germination will take 10 days at 7°C when soil reaches permanent wilting point.

The germination process in a seed may stop and start in response to available moisture. Therefore, seeds that have taken up water and entered Phase 2, but not reached Phase 3, remain viable if the soil dries out. This can happen when dry sowing is followed by a small amount of rain that keeps the soil moist for a few days before drying out. When the next rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2, so that germination is rapid.

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.

<sup>5</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

If the seedbed dries out before the coleoptile has emerged, the crop needs to be monitored to determine whether it will emerge, so 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. The 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 formation of soil crusts. Stubble retention also encourages biological activity and increases the amount of organic matter, which improves the stability of the soil by binding the soil particles together.<sup>6</sup>

## 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 range for wheat 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.

Wheat 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 before visible germination. At 10°C, it takes 3.5 days.

Table 1: Degree-days required for germination and emergence

Source: J Passioura (2005)

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

#### 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 is one reason why there is variation in emergence and establishment in the different wheat-growing areas.

#### Establishment

Plant emergence and establishment are the starting points of crop growth. 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.

Under 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.

<sup>6</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

Table 2 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.<sup>7</sup>

Table 2: Number of wheat plants established at various soil temperatures

The difference between plant establishment at 20.2°C and 33.2°C is statistically significant

Mean max. soil temp. (°C)	No. of plants established (plants/m <sup>2</sup> )
20.2°C	315.3
33.2°C	256.7
42.2°C	89.8

### 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, making it permeable to oxygen. This means that 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.<sup>8</sup>

### 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. Sowing rate needs to vary according to the 1000-grain weight for each variety, in each season, in order to achieve desired plant densities. Growers or their advisers need to weigh seeds to determine applicable sowing rates to their region.

Weather-damaged seed is more likely to have reduced germination and emergence. Further reduction may be caused by stress from azole seed dressings (a group of fungicides containing the chemical called azole), deep sowing and low soil moisture.<sup>9</sup>

### 4.3.4 Coleoptile length

The length of the coleoptile is determined more by genetics than by seed size or protein. Most modern, semi-dwarf wheats have a dwarfing gene (*Rht1* or *Rht2*) that reduces plant height, increases resistance to lodging and increases the ratio of grain weight to aboveground dry matter (harvest index). However, these genes also produce short, weak coleoptiles, usually ≤70 mm long, and poorer seedling vigour. Figure 2 presents a

<sup>7</sup> 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/Proccrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Proccrop-wheat-growth-and-development.pdf)

<sup>8</sup> 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/Proccrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Proccrop-wheat-growth-and-development.pdf)

<sup>9</sup> 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/Proccrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Proccrop-wheat-growth-and-development.pdf)

comparison of the average coleoptile lengths in varieties with the *Rht2* dwarfing gene, the *Rht8* alternative dwarfing gene, and a non-dwarfing gene, *Rht*.<sup>10</sup>

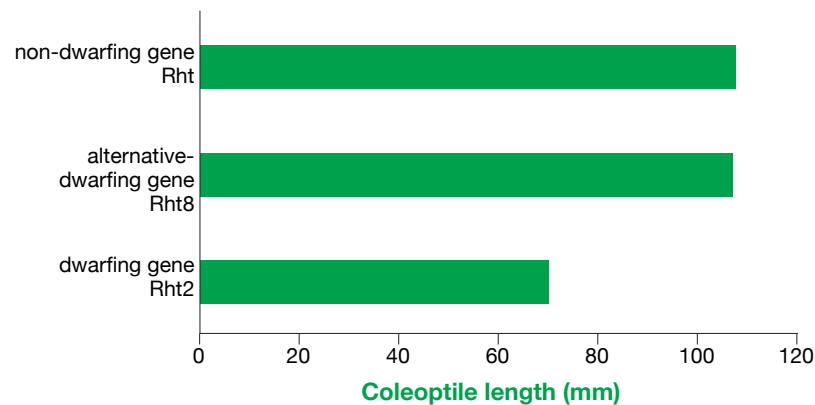


Figure 2: Comparison of coleoptile lengths for wheat varieties with the *Rht2* and *Rht8* dwarfing genes, or a non-dwarfing gene.

Plant-breeding innovations such as the long-coleoptile wheat genotypes being developed by CSIRO could deliver additional yield benefits under water-limited conditions.

Long coleoptiles can emerge from deeper in the soil profile, allowing timely sowing when effective pre-crop management such as summer weed control and stubble retention have ensured that soil water is available. However, without appropriate fallow management and stubble retention, the innovative long-coleoptile genotype provides little benefit.<sup>11</sup>

Varieties with shorter coleoptiles are less likely to emerge if sown too deeply, because the coleoptile is not long enough to break through to the surface. Fewer seedling plants emerge, reducing tiller numbers.<sup>12</sup>

Growers should always read the label of wheat-seed-dressing fungicides to determine any effects on coleoptile length.

### More information

[NSW DPI: Coleoptile length of wheat varieties](#)

## 4.3.5 Nutrition

Adequate nutrition is essential for good plant growth and development, yield, and grain quality. A soil test should be carried out before sowing to measure soil nutrients and calculate fertiliser requirements.

### Nitrogen

Nitrogen can be leached from light soil if heavy rain or continuous wet weather delays sowing. Excessive N fertiliser applied close to the seed can lead to toxicity problems. (See [GrowNotes Wheat South Section 2. Pre-planting.](#))

In the case of crops sown with wider row spacing, and with narrow points and press-wheel setups or disc seeders, the maximum N rate needs to be lower because the fertiliser becomes concentrated within the row.

Deep banding is one method of applying N fertiliser at sowing without causing seedling losses. It requires seeding systems that can separate seed and fertiliser.

### More information

[GRDC Update Papers: Nitrogen volatilisation losses—how much N is lost when applied in different formulations at different times](#)

<sup>10</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

<sup>11</sup> J Kirkegaard, J Hunt (2013) Short and long-term focus needed to lift WUE. GRDC Ground Cover Issue 103, <https://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS103/Short-and-long-term-focus-needed-to-lift-WUE>

<sup>12</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)



## Phosphorus

Phosphorus (P) is essential to seed germination and early root development. Large amounts are taken up during germination. Phosphorus deficiency at this early stage of growth significantly reduces yield potential. The plant's peak uptake of P is in the first 6 weeks.

Phosphorus is relatively immobile in the soil (unlike N), so needs to be placed near the seed and the process can be very inefficient if topdressed. Regardless of soil test results, some P is best applied at sowing in close proximity to the seed.

One method of estimating P requirement is to allow 4 kg P/t target yield. For example, a wheat crop of 3 t/ha requires 12 kg P/ha.<sup>13</sup>

### More information

[Incitec Pivot Farmer Community: Placement of fertiliser with the seed](#)

## 4.4 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, herbicides, plant growth regulators and fungicides.

### 4.4.1 Zadoks Cereal Growth Stage Key

Zadoks growth stages in relation to 10 distinct development phases are depicted in Figure 3 and examples of wheat plants at various growth stages in Figure 4.

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.

<sup>13</sup> NSW DPI District Agronomists (2007) *Wheat growth and development*. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

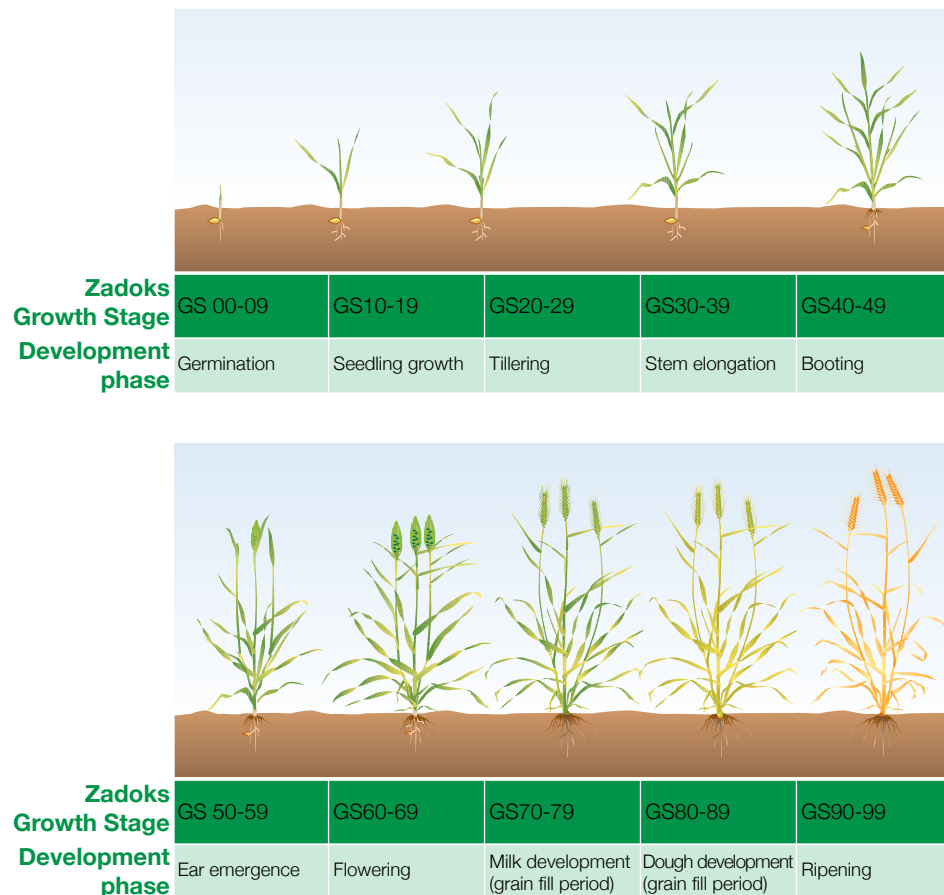


Figure 3: Zadoks growth stages.

### *Early stem elongation GS30–GS33 (pseudostem erect—third node on the main stem)*

This period is important for both timing of N application and protection of key leaves. In order 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 (because of 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 to stem elongate (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, 17, yet practically would be regarded as GS32, since this describes the most advanced stage of development.

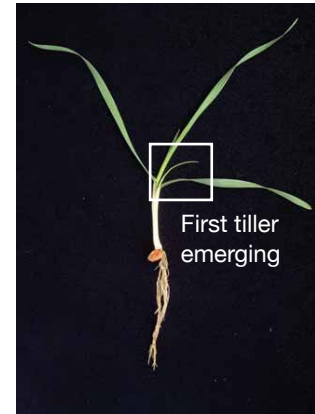
Note: After stem elongation (GS30), the growth stage describes the stage of the main stem; it is not an average of all of the tillers. This is particularly important with timing of fungicide application; for example, GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged.<sup>14</sup>



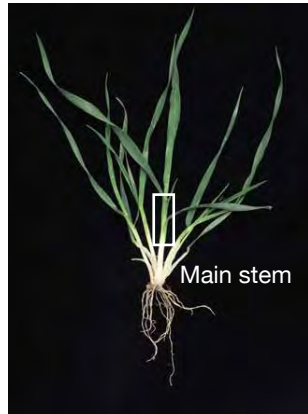
GS07 - Germinating seed with root (which forms first) and shoot



GS11 - 1st unfolded leaf (deep sown on left, correctly sown on right)



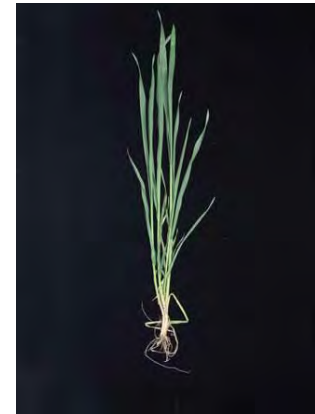
GS13 - Three unfolded leaves with first tiller emerging from first leaf axial



GS24 - Main stem and 4 tillers (note: appears to be 3 tillers, however very small tiller on right)



GS30 - Start of stem elongation (note: leaf sheath extending)



GS32 - Second node formed in main stem (approximates to leaf 3 emergence or Flag-2 or third last leaf)



GS39 - Flag leaf emergence (emergence of the most important leaf in wheat)



GS59+ Ear emergence complete

<sup>14</sup> N Poole (2005) Cereal growth stages guide. GRDC, <http://www.grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf>



GS43 - Start of the booting phase - Flag leaf sheath extending



GS49 - End of booting - leaf sheath splitting open (for awned wheats and barley 1st awns emerging)



GS55 - Ear 50% emerged on the main stem



GS69 - End of Flowering (pollen sacs visible on outside of glumes along the length of the ear)



GS71 - Start of grain fill - forming grain watery ripe



GS87 - Hard dough stage towards end of grain fill, fungicide treated on right, untreated on left

**i More information**

[GRDC: Cereal growth stages guide](#)

**▶ Video**

CSIRO VIDEO

Figure 4: Examples of wheat plants at selected growth stages.

## SECTION 5

# Nutrition and fertiliser

## More information

[GRDC Ute Guide: Winter cereal nutrition](#)

[BCG: Current GRDC-funded projects. More Profit for Crop Nutrition \(MPCN II\): Extension and training \(Southern Region\)](#)

[GRDC Fact Sheets: Better fertiliser decisions for crop nutrition](#)

[NSW DPI: BFDC Interrogator](#)

[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: Crop nutrition news](#)

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), while sulfur (S), copper (Cu) and molybdenum (Mo) may be also be lacking in some soil types and growing areas. <sup>1</sup>

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. <sup>2</sup>

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

## 5.1 Declining soil fertility

The natural fertility of cropped agricultural soils is declining over time (Figure 1). 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.

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 grain legumes 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. <sup>3</sup>

<sup>1</sup> 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>

<sup>2</sup> M Blumenthal, I Fillery (2012) More profit from crop nutrition. GRDC Ground Cover Supplement Issue 97, March–April 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>

<sup>3</sup> 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>



Figure 1: The natural fertility of cropped agricultural soils is declining over time.

## 5.2 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 test strips. This helps to build an understanding of which nutrients the crop removes at a range of yield and protein levels.

The use of paddock grain protein to detect N deficiency is well established for wheat and barley. Grain protein lower than these levels is likely to indicate loss of yield due to inadequate N supply. Wheat with a protein level >14% has had its yield limited by lack of moisture.

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.<sup>4</sup>

### 5.2.1 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 in-crop seasonal conditions and grain quality requirements;
- determine appropriate fertiliser type, rate and application method; and
- 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.<sup>5</sup>

<sup>4</sup> 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>

<sup>5</sup> 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>

### 5.3 Understanding soil pH

A soil pH in calcium chloride ( $\text{CaCl}_2$ ) of 5.2–8.0 provides optimum conditions for most agricultural plants. All plants are affected by extremes of pH, but there is wide variation in their tolerance of acidity and alkalinity. Some plants grow well over a wide pH range, whereas others are very sensitive to small variations in acidity or alkalinity.

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.<sup>6</sup>

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.<sup>7</sup> See more in the GRDC Update Paper: [pH-mapping and variable rate lime—50,000 plus hectares of experience](#).

At low pH, beneficial elements such as Mo, P, magnesium (Mg), S, K, calcium (Ca), and N become less available and others may become toxic (Figure 2). Maintain soil pH( $\text{CaCl}_2$ ) between 5.5 and 6.5 to achieve maximum P availability for wheat.<sup>8</sup>

For more information on crop-specific reactions to soil pH levels, download the New South Wales Department of Primary Industries leaflet: [Understanding soil pH](#).

<sup>6</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/167187/soil-ph.pdf)

<sup>7</sup> 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-rate-lime-50000-plus-hectares-of-experience>

<sup>8</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/167187/soil-ph.pdf)

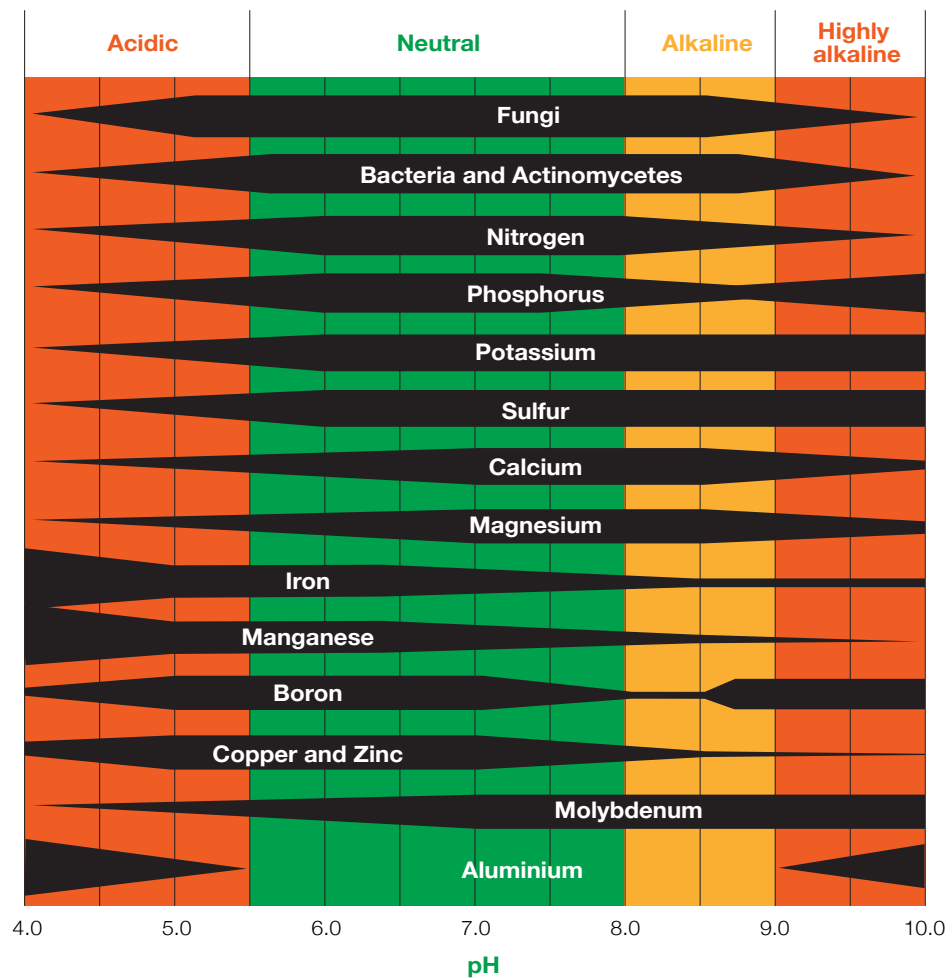


Figure 2: Effect of  $\text{pH}(\text{CaCl}_2)$  on the availability of soil nutrients. (Source: after Trough)

The two main laboratory methods employed in Australia to determine pH use either  $\text{CaCl}_2$  or water.

### 5.3.1 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  $\text{CaCl}_2$ , shaken for 1 h, and the pH is measured by using an electrode. The results are usually expressed as  $\text{pH}(\text{CaCl}_2)$ .

### 5.3.2 Soil pH in water

Distilled water is used instead of 0.01 m  $\text{CaCl}_2$ , and results are expressed as  $\text{pH}(\text{H}_2\text{O})$ . The  $\text{pH}(\text{CaCl}_2)$  test is the more accurate of the two tests, because it reflects what the plant experiences in the soil. The values of  $\text{pH}(\text{CaCl}_2)$  are normally lower than  $\text{pH}(\text{H}_2\text{O})$  by 0.5–0.9. A useful, but not consistently accurate, conversion is to subtract 0.8 from the  $\text{pH}(\text{H}_2\text{O})$  to obtain a  $\text{pH}(\text{CaCl}_2)$  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.<sup>9</sup>

<sup>9</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0003/167187/soil-ph.pdf)



## 5.4 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.<sup>10</sup>

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).<sup>11</sup>



Figure 3: Liebig's law, or law of the minimum.

Additive effects of N and P appear to account for most of the aboveground growth and yield response.<sup>12</sup>

## 5.5 Crop removal rates

Ultimately, nutrients removed from paddocks will need to be replaced to sustain production. Table 1 illustrates the different levels of nutrients extracted in both irrigated and dryland scenarios. 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 by wheat crops

	Yield	N	P	K	Ca	Mg	S	Zn
Irrigated wheat grain	7000	125	24	35	3.5	10	3	200
Dryland wheat grain	2000	40	7	10	1.5	2.8	5.5	60

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

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

<sup>10</sup> 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>

<sup>11</sup> Liebig's law of the minimum. Wikipedia, [http://en.wikipedia.org/wiki/Liebig's\\_law\\_of\\_the\\_minimum](http://en.wikipedia.org/wiki/Liebig's_law_of_the_minimum)

<sup>12</sup> 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>

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.<sup>13</sup>

## 5.6 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.<sup>14</sup>

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, sodium (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 support decisions about fertiliser rate, timing and placement.

To determine micronutrient status, plant tissue testing is usually more reliable.

### 5.6.1 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)
- KCl-40 extractable S
- 1 m KCl-extractable inorganic N, which provides measurement of nitrate-N and ammonium-N

For determining 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.

<sup>13</sup> 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>

<sup>14</sup> 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>

### More information

[GRDC: Soil testing for crop nutrition \(Southern Region\)](#)

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

### 5.6.2 Sampling depth

Soil sampling depth for most nutrient analyses is 0–10 cm. For N and S, which are highly mobile in the soil, 0–60 cm is recommended. There is increasing evidence of the value of assessing soil-based physicochemical constraints to production, including sodicity, salinity and acidity–Al, from both the surface and subsoil layers.

In some regions, evidence suggests that deep soil samples should be analysed for nutrients other than N. This is still not fully supported for the soils in the Southern Region. Deep sampling especially for S, EC and B to the depth of any root barriers is now carried out regularly.

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).

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 boron (or other nutrient constraints) and moisture. Sulfur testing at 0–10 cm is not as indicative of crop needs as 0–60 cm, and 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.

### 5.6.3 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.

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.

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. If the soil test is outside the critical range, fertiliser must be considered to maintain soil levels or to lower the risk of encountering deficiency.<sup>15</sup>

Table 2: Critical values and critical ranges (mg/kg) for the 0–10 cm sampling layer for 90% of relative yield<sup>16</sup>

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 barley	Vertosols	17	12–25
		Chromosols, Sodosols	22	17–28
		Brown/Red Chromosols	25	18–35
	Barley	Calcarosols	34	26–44
		Ferrosols	76	46–130
		All soils	18	16–19
Colwell-K	Wheat	All soils	24	21–28
		Chromosols	40	35–45
		Brown Ferrosols	64	57–70
		Kandosols	49	45–52
	Tenosols	41	32–52	
Lupin	All soils	45	43–47	
	Tenosols (WA data)	24	22–27	
KCl-40 S	Wheat	Chromosols, Kandosols, Sodosols, Tenosols, Vertosols	4.5	3.2–6.4
		NSW data (0–15 cm)	8.6	4.8–15.0
	NSW data (0–60 cm)	31	25–39	

### 5.6.4 Test strips

Test strips 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 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.

<sup>15</sup> 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>

<sup>16</sup> 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>

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. <sup>17</sup>

### 5.6.5 Rules of thumb

Choose the same soil test package each year (including methods); otherwise, comparisons between years will be useless. 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.

For monitoring, sampling needs to 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](#). <sup>18</sup>

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

### 5.6.6 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. Primary wheat roots can grow to a depth of 2 m and can extract N from this level. <sup>19</sup>

Test results are a great indication of N, but historical grain yield and protein levels from the paddock can also be used to assist N-requirement decision making. <sup>20</sup>

Environmental conditions, including temperature, time and rainfall events can affect starting soil N; therefore, it is important to test later in the summer or 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
2. Ammonium, e.g. anhydrous ammonia, sulfate of ammonia, ammonium nitrate
3. Amide, e.g. urea
4. Organic, e.g. blood and bone, meat meal

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

<sup>17</sup> 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>

<sup>18</sup> GRDC (2013) Better fertiliser decisions for crop nutrition. Crop Nutrition Fact Sheet, GRDC, 4 November 2013, <http://www.grdc.com.au/GRDC-FS-BFDCN>

<sup>19</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

<sup>20</sup> 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>

## More information

[GRDC Fact Sheets: Crop nutrition – phosphorus management](#)

### 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<sup>21</sup>

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).

## 5.6.7 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 was the original test for P response in wheat in northern NSW. It is used with the PBI to indicate the sufficiency and accessibility of P in the soil.

### 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.

### 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.

### 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.<sup>22</sup>

## 5.7 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.

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

### More information

[Soil Quality Fact Sheet: Soil phosphorus availability by DGT](#)

### More information

[Soil Quality: South Australia—phosphorus buffering index](#)

[Research paper: A simple phosphorus buffering index for Australian soils](#)

<sup>21</sup> 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>

<sup>22</sup> GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, January 2014, <https://www.grdc.com.au/~media/34D1397472234B6F8B195732A963F047.pdf>

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.<sup>23</sup>

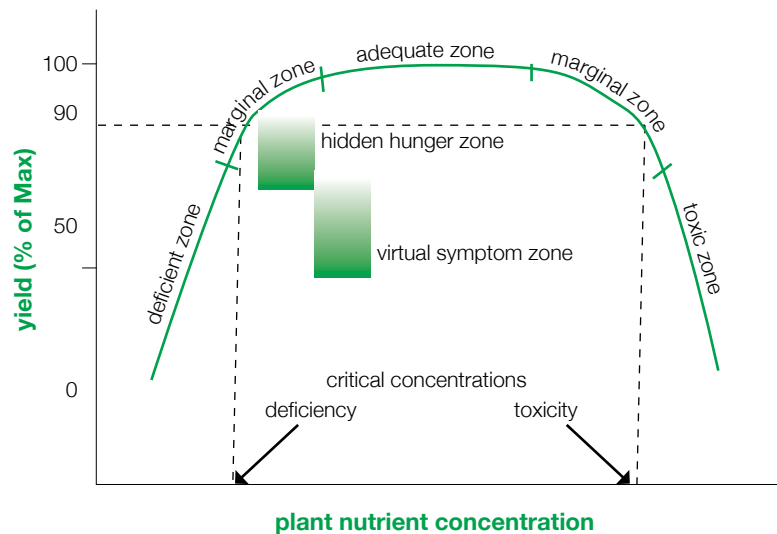


Figure 4: Generalised grain yield response curve to plant nutrient concentration.

## 5.8 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.

There is generally a poor relationship between pre-sowing soil-test N and yield response of wheat and canola to applied N. This is usually due to the effect of stored water and in-season rainfall.

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 *Yield Prophet*<sup>®</sup> and *Select Your Nitrogen* (SYN). *Yield Prophet*<sup>®</sup> requires a detailed characterisation of the physical and chemical properties of the soil profile explored by the roots.<sup>24</sup>

### 5.8.1 Nitrogen supply and grain protein content

Nitrogen is a primary constituent of protein; therefore, adequate soil N supply is essential for producing wheat with a high protein content. Supply of N is shaped by a number of factors in the farming system (Figure 5) and the N cycle (Figure 6).

<sup>23</sup> GRDC (2013) Micronutrients. Northern, Southern and Western Regions. Crop Nutrition Fact Sheet, GRDC, November 2013, <http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients>

<sup>24</sup> GRDC (2014) Soil testing for crop nutrition. Southern Region. Crop Nutrition Fact Sheet, GRDC, January 2014, <http://www.grdc.com.au/GRDC-FS-SoilTestingS>

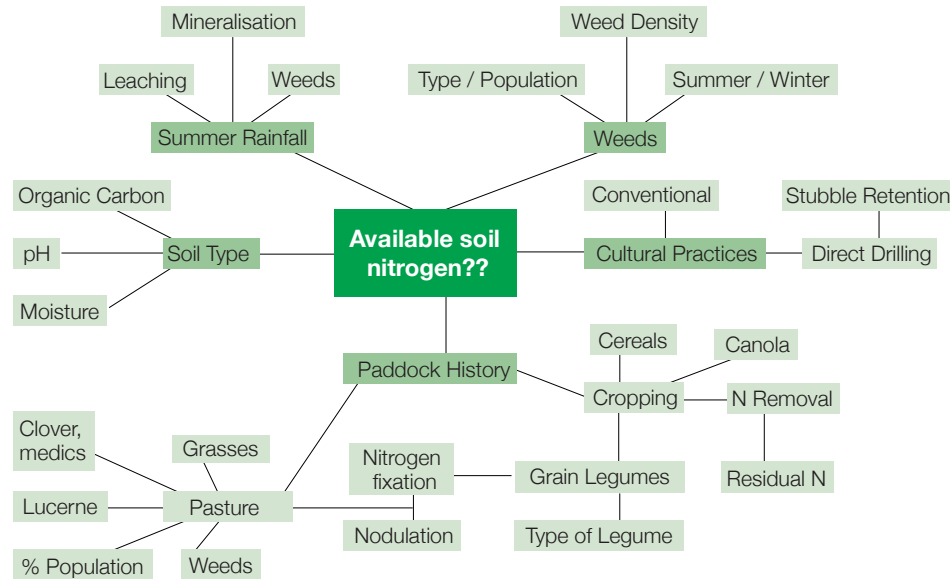


Figure 5: Factors influencing available soil nitrogen. (Source: Incitec Pivot Ltd)

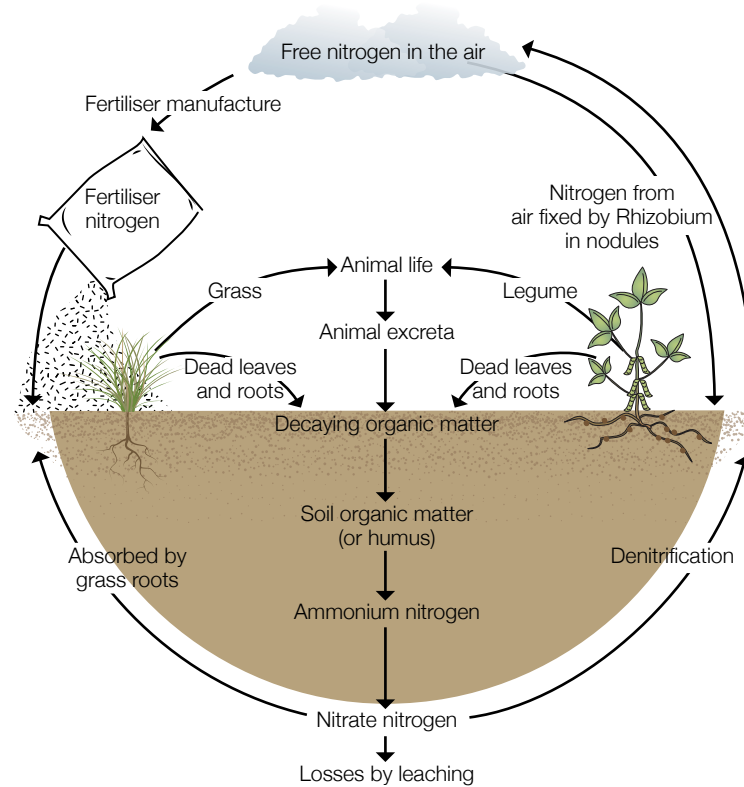


Figure 6: The soil nitrogen cycle.

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.



Cropping advisors are a good source of support in determining fertiliser application strategies.<sup>25</sup>

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 7). 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.

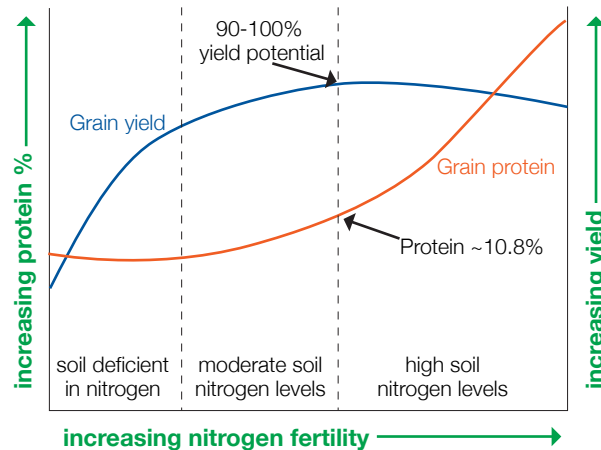


Figure 7: Relationship between grain yield and protein. (Source: Incitec Pivot Ltd)

### More information

GRDC Update Papers:  
[Where does fertiliser nitrogen finish up?](#)

## 5.8.2 Nitrogen deficiency symptoms

Description:

- Plants are pale green with reduced bulk and tiller formation (Figures 8 and 9).
- Symptoms first occur on 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.

### 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.

<sup>25</sup> Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

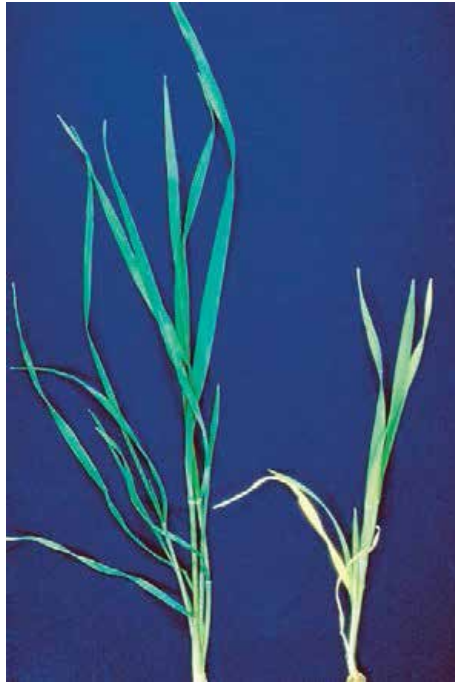


Figure 8: Adequate (left) and inadequate (right) nitrogen nutrition. (Photo: Mel Mason, Agriculture WA)<sup>26</sup>



Figure 9: Inadequate nitrogen nutrition expressed as pale green plants with reduced bulk and tiller formation.

### 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.<sup>27</sup>

### 5.8.3 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

<sup>26</sup> GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

<sup>27</sup> GRDC (2007) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

ammonium ions (NH<sub>4</sub><sup>+</sup>). If there are insufficient adsorption sites at the soil surface for the ammonium ions, ammonia (NH<sub>3</sub>) 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 (high-pH) soils, in which hydroxyl (OH<sup>-</sup>) ions are present in high concentrations.<sup>28</sup>

Many farmers practice pre-season broadcasting and in-season topdressing of wheat crops. Splitting N application between sowing and in-crop allows growers to lower their financial risk on fertiliser application 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 all of the N really lost to the air in 1 or 2 days? Literature from international research lists the range of measured losses from 0% to almost 100%, but very few instances of losses >~40% of that applied, with most studies finding only ~10% loss.

In the 2008 and 2009 GRDC Adviser Updates, researchers detailed the factors that drive the process of N volatilisation from fertiliser, along with the results of some laboratory incubation experiments.

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 (CaCO<sub>3</sub>). Lime in the soil reacts directly with ammonium sulfate, increasing loss.
5. 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.
7. 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.
10. 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.

<sup>28</sup> Incitec Pivot Limited, <http://www.incitecpivot.com.au/>

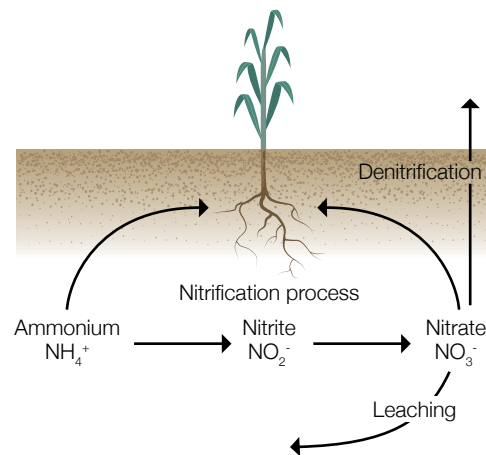


Figure 10: The nitrification process.

Saturated soil conditions between fertiliser application and crop growth can lead to significant N losses from the soil through denitrification (Figure 10). The gases lost can be nitric oxide (NO), nitrous oxide (N<sub>2</sub>O) and di-nitrogen (N<sub>2</sub>). 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.<sup>29</sup>

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.<sup>30</sup>

### 5.8.4 Nitrogen-use efficiency

Efficient use of N is crucial to economic production of wheat. 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.<sup>31</sup>

### 5.8.5 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.

<sup>29</sup> 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>

<sup>30</sup> 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>

<sup>31</sup> R Brill, M Gardner, G McMullen (2012) Comparison of grain yield and grain protein concentration of commercial wheat varieties. GRDC 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>

#### More information

[Soil Quality Fact Sheet: Soil nitrogen supply](#)

## in focus

### 5.8.6 Effectiveness of late nitrogen application

Results of a GRDC-funded Southern Farming Systems (SFS) 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.
- Given the total amount of N applied to the crop and the soft finish during the trial, all treatments met Australian Premium White (APW) specification for protein (>10.5%).
- 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 are facing 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 11 below.<sup>32</sup>

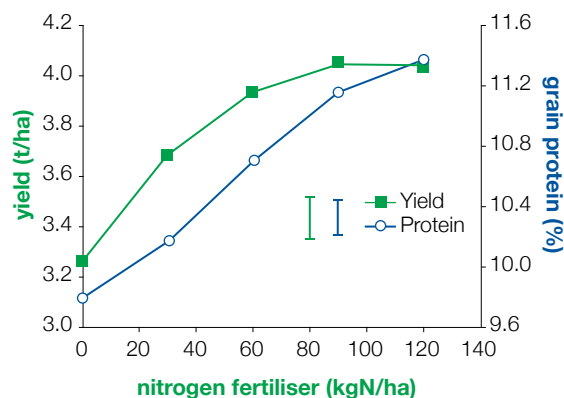


Figure 11: Grain yield (t/ha) and protein concentration (%) from 10 wheat varieties with varying rates of applied nitrogen (Brill et al. 2012).

<sup>32</sup> 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](http://www.sfs.org.au/trial-result-pdfs/Trial_Results_2013/2013_LateNitrogenInWheatBetterLateThanNeverHowLateIsTooLate_VIC.pdf)

## 5.9 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 wheat. 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 time. 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 wheat anticipated. The application is then adjusted in the light of soil test results.<sup>33</sup>

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 Decision 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.

Soil critical-P test value is not affected by wheat yield except where yields are very low (<1 t/ha).

On highly calcareous soils (Calcarosols), the DGT-P soil test provides a better prediction of crop response to fertiliser than Colwell-P.<sup>34</sup>

### 5.9.1 Phosphorus deficiency

Description (Figures 12 and 13):

- 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.<sup>35</sup>

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

<sup>33</sup> Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat>

<sup>34</sup> 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>

<sup>35</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

### 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](#)

Phosphorus deficiency is more likely to occur after a long fallow due to low numbers of arbuscular mycorrhizal fungi (AMF) in the soil. These AMF are the beneficial soil fungi that help plant roots take up both P and Zn.<sup>36</sup>



Figure 12: Adequate (left) and inadequate (right) phosphorus nutrition. (Photos: Nigel Wilhelm, SARDI)<sup>37</sup>



Figure 13: Phosphorus deficiency on the right-hand side of the image. (Photo: Nigel Wilhelm, SARDI)

<sup>36</sup> DAF Qld (2010) Other elements of crop nutrition—phosphorus. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/other-nutrition>

<sup>37</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

### Similar symptoms

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

### Contributing factors

Low available soil P and/or low AMF.<sup>38</sup>

## 5.9.2 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 (Table 3). Hence, it is important to apply 'starter fertilisers' with the seed, so that the seed has a ready source of P for its development.

Subsequent P requirement is much larger, and largely mirrors the accumulation of crop biomass. As a rule, crops require ~5 kg P 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.

The need for P fertiliser can be determined by using soil tests (0–10 and 10–30 cm) and/or test strips of fertiliser.<sup>39</sup>

Table 3: 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

## 5.9.3 Phosphorus availability

A key consideration for growers with regard to fertiliser management is how much P the stubble will supply, 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.

### More information

[GRDC Fact Sheets: Soil testing for crop nutrition \(Southern Region\)](#)

<sup>38</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

<sup>39</sup> DAF Qld (2010) Other elements of crop nutrition—phosphorus. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/other-nutrition>



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 using 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 stubble and microbial uptake and release. The presence of different chemical P forms in the stubble is likely to influence the proportion of P that undergoes direct release or microbial uptake and decomposition.

Research results indicate 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.<sup>40</sup>

#### 5.9.4 Long-fallow disorder

When fallow length exceeds 12 months through crop rotation or drought, moderate to high rates of P fertiliser are often required to prevent long-fallow disorder affecting the crop. A suggested rate is 10 kg P/ha. Wheat following canola may also benefit from higher P rates because canola is not a host of AMF. For more information, see [GrowNotes Wheat South Section 1. Planning and paddock preparation](#).

#### 5.9.5 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 4 shows the actual rate of fertiliser product required to apply various rates of P.

Table 4: Products used primarily to supply phosphorus

Product trade name	% P in product	Required rate of application of P (kg/ha)				
		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

#### 5.9.6 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 14 shows wheat roots responding to a band of P placed evenly distributed (between the blue dots) in a column ~0.3 m long and, by contrast, the root response to a granule of P placed at a similar depth in a similar pot.

<sup>40</sup> S Noack, M McLaughlin, R Smernik, T McBeath, R Armstrong (2012) The value of phosphorus in crop stubble. GRDC Update Papers, 23 February 2012

These technologies 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 it in moist soil.<sup>41</sup>

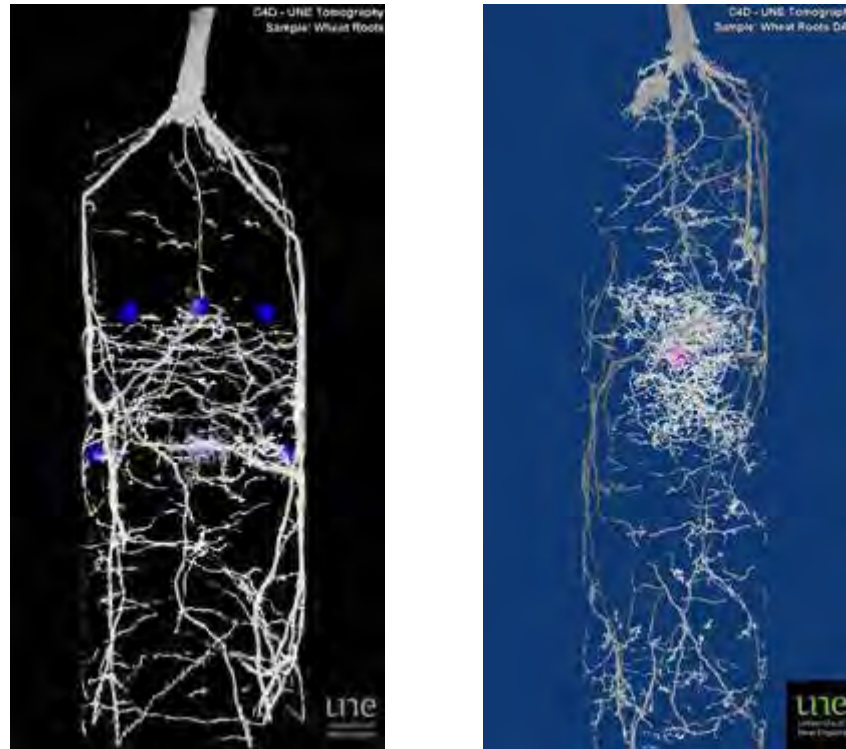


Figure 14: 3D Computer-aided tomographs of cereal root systems supplied with P in a diffuse band (left panel) or in a granule (right panel) after 30 days of growth.

### 5.9.7 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-fertiliser-use 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. Research in South Australia on highly calcareous soils (20–90% CaCO<sub>3</sub>) has shown possible benefits of using liquid fertilisers over the traditional granular forms.<sup>42</sup>

Soils in northern NSW have CaCO<sub>3</sub> concentrations much less than those found in the calcareous soils of South Australia. Researchers reported on dry matter responses to liquid and granular P fertilisers from soils collected from around Australia. Six soils from the northern grains region were studied, with CaCO<sub>3</sub> levels ranging from undetectable to 1.3%. Five of these soils had positive dry matter responses to liquids, which was greater than when granular products were used.

<sup>41</sup> 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>

<sup>42</sup> B Manning, J Hunt, G McMullen (2012) Phosphorus fertiliser—Does product choice matter? Northern Grains Region Trial Results Autumn 2012, pp. 83–86. NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0019/430291/Northern-grains-region-trial-results-autumn-2012.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/430291/Northern-grains-region-trial-results-autumn-2012.pdf)

One of the key conclusions was that grain yield responses to liquid P need to be assessed under field conditions. The aim of these trials was to determine whether there is any benefit in using liquid instead of solid P, and whether the volume of water used to apply liquid P has an influence on yield by increasing the volume of soil in which the P is distributed at higher volumes of water. Because most P is applied as starter fertiliser containing Zn, treatments plus and minus Zn were also included.

Grain yield responses to fertiliser P were not as clear as was expected from this site. The wet seasonal conditions may have influenced the P response, with increased root growth resulting in a greater capacity of the crop to utilise existing soil P reserves.

There was no difference between the types of fertiliser used with respect to plant growth or grain yield. When deciding whether to use liquid P fertilisers, the additional cost of equipment to use these fertilisers also needs to be taken into account.<sup>43</sup>

On most soils, although liquid P might initially increase dry matter production, it offers no agronomic advantage or yield increase over granular P. 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 trial data.

### 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 of traditional fertiliser, and should be added to budget comparisons.<sup>44</sup>

## 5.10 Sulfur

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

Sulfur inputs to cropping systems have declined with the use of triple superphosphate (TSP) and mono- and di-ammonium phosphate (MAP and DAP), which are low in S. 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.

Interrogation of wheat trial data in the BFDC database found that the critical soil-S test value (measured in the 0–10 cm soil layer) is poorly defined when considered across all soil types.<sup>45</sup>

<sup>43</sup> B Manning, J Hunt, G McMullen (2012) Phosphorus fertiliser—Does product choice matter? Northern Grains Region Trial Results Autumn 2012, pp. 83–86. NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0019/430291/Northern-grains-region-trial-results-autumn-2012.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/430291/Northern-grains-region-trial-results-autumn-2012.pdf)

<sup>44</sup> GRDC (2009) Profitable nutrient use starts with knowing the reserve. Targeted Nutrition at Sowing Fact Sheet, GRDC, 2009, <http://www.grdc.com.au/Resources/Bookshop/2010/10/-/media/27AA21276EE7425FA368BE48A95B5676.pdf>

<sup>45</sup> 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>

### 5.10.1 Deficiency symptoms

Description (Figures 15 and 16):

- Young plants are pale green or yellow with only limited stunting.
- Upper leaves of mature plants are pale green to yellow, with the lower leaves remaining green (unlike N deficiency).
- Tiller production is not affected, although mature tillers will produce small heads.
- Whole plant is pale green with a greater yellowing in the newest leaves, which are a 'butter' yellow.
- Whole leaves are light yellow with no stripes or green veins.
- With severe deficiency, leaf tips of old leaves can die.

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.<sup>46</sup>

#### 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 mineralisation and uptake of S. Acid sandy soils are subject to leaching of S. Fertilisers such as DAP and MAP are low in S.<sup>47</sup>



Figure 15: Sulfur-deficient plants (first three from left) compared with a plant receiving adequate S nutrition. (Photo: J Yeates, DAFWA)

<sup>46</sup> 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>

<sup>47</sup> 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 16: Sulfur-deficient wheat crop. (Photo: Matthew Whitney, Dodgshun Medlin Ag Management)

## 5.11 Potassium

Potassium (K) 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.<sup>48</sup>

Generally, in the Southern Region, cropping soils are unresponsive to additions of K. However, as crops continue to mine K from soils, this may change in the future. 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.

The critical values for Colwell-K in wheat vary with soil type from ~40 mg/kg on Chromosols, to ~49 mg/kg on Kandosols and ~64 mg/kg on Brown Ferrosols.

There was some evidence in the BFDC analysis that critical values increased with increasing crop yield and on soils with no acidity constraints to root growth.<sup>49</sup>

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.<sup>50</sup>

<sup>48</sup> 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>

<sup>49</sup> 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>

<sup>50</sup> 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.

### 5.11.1 Deficiency symptoms

- Young plants grow very slowly and they are often stunted.
- In older plants, the lower leaves exhibit a marginal 'scorch', with yellow to brown margins towards the leaf tips.
- Potassium-deficient plants may also lodge more readily.<sup>51</sup>
- The whole plant has reduced vigour and spindly growth.
- Specific symptoms first appear on the oldest leaves, which are speckled along their whole length, quickly spreading to the tip and margins in severe cases.
- As leaves die back from the tip and margins, a spear-shaped pattern of green remains (clearest characteristic).
- Old leaves often die completely and plants appear to hay-off prematurely.

Figure 17 shows the degree of deficiency from adequate, yellow mottling, death of leaf tips and the green-spear effect.

#### 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.<sup>52</sup>



Figure 17: The leaf on the left shows adequate potassium nutrition; the others show inadequate K. (Photo: Noel Grundon, QDPI)<sup>53</sup>

<sup>51</sup> 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>

<sup>52</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

<sup>53</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

### 5.11.2 Critical levels and inputs

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

Remember that, like P, K is effectively immobile in the soil, so profiles are tending 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 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.

Once K fertility of the surface layers has been restored, deep application is the best way to apply K fertilisers to maintain 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.<sup>54</sup>

Field studies have examined crop yield–soil-test K relationships for a Ferrosol, and glasshouse studies have been used to determine patterns of K accumulation in Ferrosols with different K status.

Crops varied markedly in critical soil-test K for grain yield, but there was no significant response to K placement in either grain or cotton-seed yield. Patterns of K accumulation differed between crop species. Although all crops exhibited faster relative accumulation of K than of biomass, relative K accumulation rates in maize were much greater than in wheat or sorghum. This was related to the more indeterminate growth habit of wheat and sorghum resulting from addition of tillers compared with maize. Delayed access to surface-applied K until flowering in all species resulted in significant late-crop K uptake but no significant biomass or grain yield responses, even under conditions of severe K deficiency.<sup>55</sup>

#### More information

[BFDC Interrogator: Case study: potassium in wheat](#)

## 5.12 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.

<sup>54</sup> 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>

<sup>55</sup> RF Brennan, MJ Bell (2013) Soil potassium–crop response calibration relationships and criteria for field crops grown in Australia. *Crop and Pasture Science* 64, 514–522, <http://www.publish.csiro.au/paper/CP13006.htm>

- 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.<sup>56</sup>

### 5.12.1 Zinc

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 wheat are 8–10 mg/kg but the response curve is very steep. Zinc supplements can be applied with fertiliser as zinc oxide, chelated Zn or zinc sulfate. The last two products are soluble and can be used for foliar applications. Product efficacy varies with the time and placement of application.<sup>57</sup>

Deficiency description (Figures 18 and 19):

- Plants are stunted with short, thin stems and usually pale green leaves.
- Young to middle leaves develop yellow patches between the mid vein and the edge of the leaf, extending lengthways towards the tip and base of the leaf.
- These areas eventually die turning pale grey or brown.
- Plants take on a water-or diesel-soaked appearance.
- Affected areas may remain separate or join, with the death of the entire central leaf area; 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 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.<sup>58</sup>

<sup>56</sup> GRDC (2013) Micronutrients. Crop Nutrition Fact Sheet GRDC, 4 November 2013, <http://www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients>

<sup>57</sup> 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>

<sup>58</sup> 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 18: Zinc deficiency in wheat. (Photo: Matthew Witney, Dodgshun Medlin Ag Management)



Figure 19: Zinc deficiency symptoms on wheat leaf. (Photo: Matthew Witney, Dodgshun Medlin Ag Management)

### 5.12.2 Copper

Copper is essential for chlorophyll formation and pollen production as well as baking quality. 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 is high iron (Fe), manganese (Mn) or Al in the soil. Critical tissue levels have been reported as <1.5 mg/kg at the youngest expanded blade in wheat.<sup>59</sup>

Deficiency symptoms in wheat include (Figures 20 and 21):

- wilting despite ample water supply
- leaf-tip dieback of youngest leaves with leaves becoming tightly twisted
- ear-tip dieback, where the top of the head turns white or yellow (the remainder of the head stays green, but may not set grain)
- white heads and delayed maturity, and melanism (blackening) of stems
- ear branching
- upper node tillering<sup>60</sup>

Detailed description:

- Heads have 'rat-tail' appearance with full grain in the base, shrivelled grains in the middle and a withered dead tip. Gaps in heads can also be present due to unfertilised embryos amongst fertilised grains (Figures 22 and 23).
- With marginal deficiency, grain is shrivelled, with the stem and head bending over.
- Grain yield reduced due to reduced pollen fertility.
- Whole plants are light green and begin to wilt at early tillering despite adequate soil moisture.
- First characteristic symptoms are sudden death and withering (curling) of the tip and up to half the length of young leaves.
- Tips of young leaves hang down and turn yellow.
- Base of leaf can remain green until the crop ripens.
- Old leaves remain green and apparently healthy.
- With severe deficiency, new growth withers before unfolding; tillering is reduced, stems are weak.
- Length of stems is reduced, and stem, nodes and spikelet glumes can purple; tillering from base of upper leaves.
- Mature plants are a dull grey-black colour with white heads compared with bright yellow appearance of healthy crop.

#### 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).<sup>61</sup>

<sup>59</sup> 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>

<sup>60</sup> 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>

<sup>61</sup> 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 20: Copper deficiency. (Photo: Doug Reuter, CSIRO)



Figure 21: Copper deficiency symptoms on wheat leaves. (Photo: Doug Reuter, CSIRO)



Figure 22: 'Rat-tail' appearance of heads with full grain in the base indicating copper deficiency. (Photo: Ross Brennan, DAFWA)



Figure 23: Deformed heads indicating copper deficiency. (Photo: Ross Brennan, DAFWA)

### 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.<sup>62</sup>

### 5.12.3 Boron

Key points:

- Boron is essential for germination and sugar metabolism.
- Lucerne is more susceptible to deficiency than canola and wheat is less susceptible than canola.
- Symptoms of deficiency include stem splitting and poor seedset.
- 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:

- Newer leaves split along the leaf close to the midrib.
- Edges of young leaves have a saw-tooth effect (Figure 24).
- Severe deficiency causes increased tillering, new shoots look water-soaked and paler, and leaves are distorted along edges; finally, new growth dies and shoots wither.

#### Similar symptoms

Copper and Ca deficiency show similar symptoms of shoots withering.<sup>63</sup>

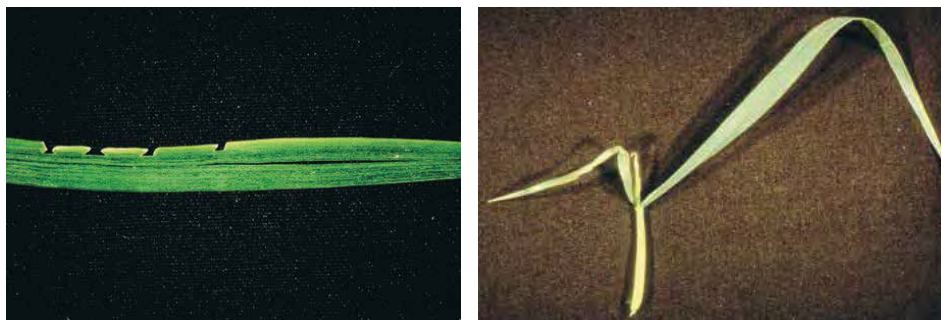


Figure 24: Deformed leaves indicating boron deficiency.

#### 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 25). Symptoms often do not appear in early vegetative growth.

#### Similar symptoms

Nitrogen and K deficiency appear similar but these are most obvious early in crop development (before boron toxicity symptoms normally appear).

#### Contributing factors

Boron toxicity can occur with high boron levels in subsoil and when growing boron-intolerant varieties.<sup>64</sup>

<sup>62</sup> 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>

<sup>63</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

<sup>64</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

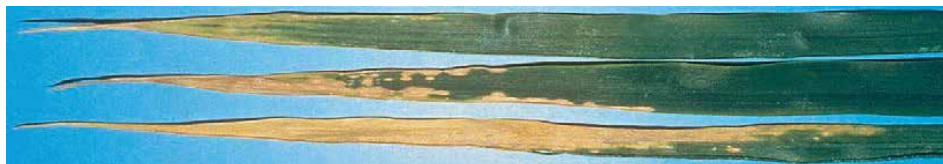


Figure 25: Symptoms of boron toxicity. (Photo: Brian Cartwright, CSIRO)

### 5.12.4 Iron

Key points:

- Iron is an essential component of chlorophyll and respiratory enzymes.
- Legumes are more responsive to Fe than are cereals.
- 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:

- New leaves have striping, with alternate yellow and green stripes down the length of the leaf (Figures 26 and 27).
- Under severe Fe deficiency, new growth may turn white.
- New growth remains yellow for some time before the leaf begins to die.

#### Similar symptoms

Magnesium deficiency usually has a 'bead' appearance, and Mn deficiency causes yellow striping of new growth but the striping is not as pronounced.

#### Contributing factors

Contributing factors include highly calcareous soils, cold and wet conditions, and application of high rates of lime.<sup>65</sup>

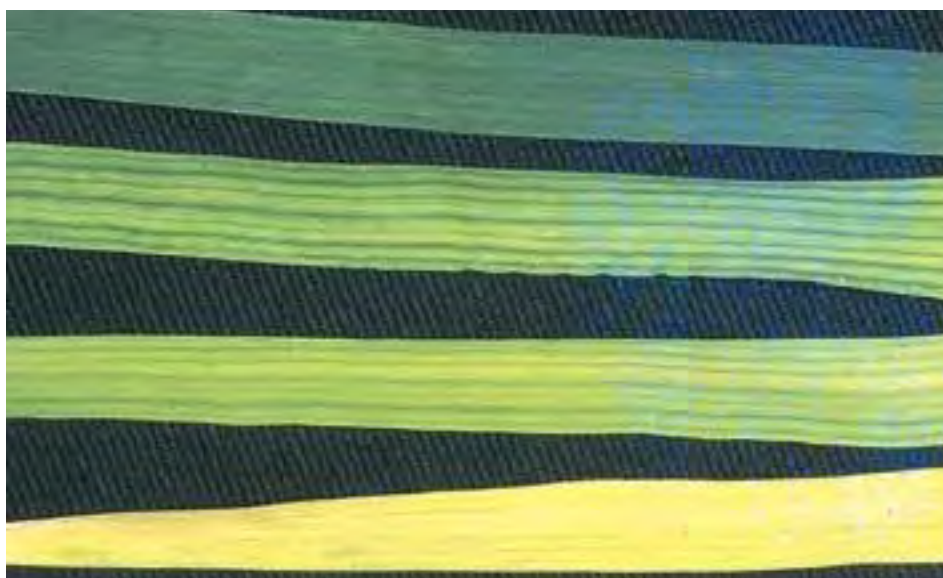


Figure 26: Iron deficiency on wheat leaves. (Photo: Hungry Crops, QDPI)

<sup>65</sup> 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 27: Iron deficiency in wheat crop. (Photo. Mark Seeliger, PIRSA)

### 5.12.5 Manganese

#### 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:

- It often appears as patches of pale, floppy wheat in an otherwise green, healthy crop (Figure 28).
- New leaves are pale compared with old leaves and appear limp, with some withering of new shoots.
- Pale green–yellow striping appears at the base of the youngest fully opened leaf.
- As leaves develop, the striping becomes more pronounced, particularly in the middle of the leaf where patches begin to die and the leaf collapses (Figure 29).
- By this stage, the leaves are usually located on the middle of the plant.
- Maturity is delayed.



Figure 28: Manganese deficiency in wheat crop.



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



### Similar symptoms

Iron deficiency causes striping but is more even and more vivid with no flecking.

### 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.<sup>66</sup>

### Manganese toxicity

Manganese toxicity symptoms include grey flecks or either yellow or brown spots developing on leaves (Figure 30).

### 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 ( $\text{pHCaCl}_2 < 4.5$ ) and in wet, poorly drained soils; these conditions make Mn more available for plant uptake.<sup>67</sup>

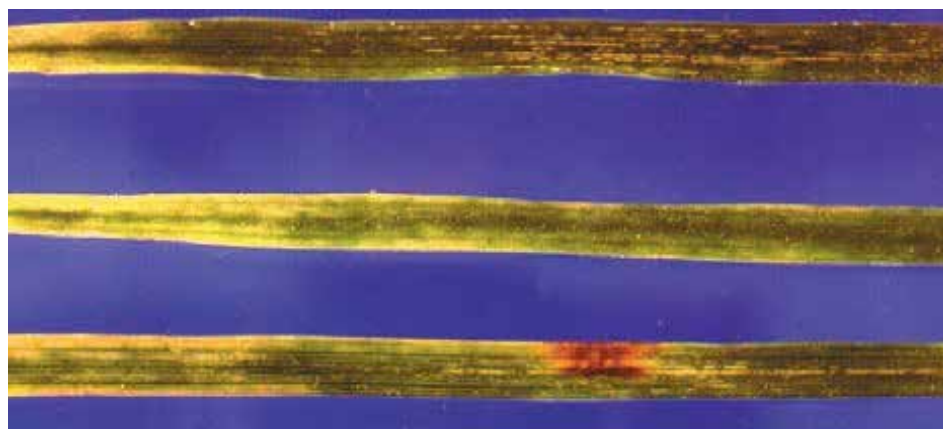


Figure 30: Manganese toxicity. (Photo: Brendan Scott, Agriculture NSW)

## 5.12.6 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.
- Tissue levels of 0.28–0.55 mg Mo/kg in the youngest mature leaf are adequate for canola, and <0.1 mg/kg at mid–late tillering in wheat is considered deficient.
- Very small quantities (50 g/ha) applied with fertiliser are usually sufficient, usually in the form of molybdenum trioxide. Sodium or ammonium molybdate can be used as sprays.<sup>68</sup>

<sup>66</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

<sup>67</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

<sup>68</sup> Incitec Pivot. Molybdenum fact sheet. Fertfacts. Incitec Pivot, <http://www.incitecpivotfertilisers.com.au/en/Agronomy/-/media/Files/IPF%20Migration/FertFacts/MolybdenumFS/MolybdenumFSV3IPLLM15102009.ashx>



Figure 31: Wheat grown without (left) and with molybdenum. (Photo: Snowball and Robson 1988)

Description of deficiency (Figure 31):

- 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

Copper deficiency can cause wilting, delayed maturity and empty heads. Crimping on flag leaf is often confused as a symptom of Mo deficiency, but is usually a physiological effect.

### Contributing factors

Factors include acidic soils, moderate to high levels of available soil N, and soils high in iron and aluminium oxides.<sup>69</sup>

## 5.12.7 Magnesium

Description of deficiency (Figure 32):

- Plants appear unthrifty and water-stressed.
- New wheat leaves are pale and will soon yellow, remaining unopened with a twisted appearance.
- Yellowing becomes mottled (spots or beads) and finally the leaves die, but remain upright.
- Oldest leaves also become a mottled yellow and in some cases reddish along the leaf margins.
- With severe deficiency, the entire length of the leaf will remain folded or rolled.

<sup>69</sup> GRDC (2014) Winter cereal nutrition: the Ute Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide>

### Similar symptoms

Potassium deficiency symptoms also include unthrifty and water-stressed plants, but yellowing and death only occur on the older leaves.

### Contributing factors

Applications of high rates of high-quality lime can contribute. Magnesium deficiency is rare in broadacre agricultural crops.<sup>70</sup>



Figure 32: Magnesium deficiency symptoms. (Photos: Brendan Scott, Agriculture NSW)

<sup>70</sup> 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


**More information**

[Agriculture Victoria: Diagnostic services](#)

[GRDC: Weed Webinars](#)

[GRDC: Weed ID. The Ute Guide](#)

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, equivalent to ~20% of the gross value of the Australian wheat crop. Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry.<sup>1</sup>

Weed control is essential if wheat is to make full use of summer rainfall, and in order 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.<sup>2</sup>

Weed control is important, because weeds:

- rob the soil of valuable stored moisture
- rob the soil of nutrients
- cause issues at sowing time, restricting access for planting rigs (especially vine-type weeds such as melons, 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
- can 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 for 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, first 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 weed-bank status, soil types in relation to herbicide used, and cropping

<sup>1</sup> GRDC (2014) Integrated weed management hub. GRDC, [www.grdc.com.au/weedlinks](http://www.grdc.com.au/weedlinks)

<sup>2</sup> DAF Qld (2012) Wheat—planting information. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/planting-information>

## **i** More information

[NHT: Introductory weed management manual](#)

[NSW DPI: WeedWise](#)

[Sydney Royal Botanic Gardens Herbarium: PlantNET](#)

[WA Herbarium: FloraBase](#)

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.

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.<sup>3</sup>

### 6.1.1 Review past actions

The historical level of selection pressure can be valuable information for managers to gauge which weed–MOA groups 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 1). 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.<sup>4</sup>

<sup>3</sup> GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, <http://www.grdc.com.au/Resources/IWMhub>

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

## More information

[WEEDpak Weed ID guide](#)

[Weeds Australia: Weed identification tool](#)

[Weeds Society of WA: Western Weeds](#)

## Video

[Weed ID App](#)

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

Herbicide Group	Typical years of application	Resistance risk
A (fops/dims/dens)	6–8	High
B (sulfonyleureas, 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.<sup>5</sup>

### 6.1.3 Identify weed management opportunities

Identify which different herbicide and non-herbicide tactics could be cost-effectively added to the system and at what point in the crop sequence these can be added. For further information on the different IWM tactics see: [IWM Section 4: Tactics](#).<sup>6</sup>

#### *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>.<sup>7</sup>

### 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?<sup>8</sup>

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

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

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

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

## More information

[NSW DPI: Weed management in winter crops](#)

[NSW DPI: Weed management in summer crops](#)

## GRDC Update papers

[Biology and management of summer weeds](#)

[Brome and barley grass management in cropping systems of southern Australia](#)

[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](#)

[Hitting the right target—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](#)

## 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. Two simulation tools in use are the [Weed Seed Wizard](#) and [RIM](#).

Combine ideas using a rotational planner, or test them by using decision-support software such as RIM and Weed Seed Wizard.<sup>9</sup>

### *Weed Seed Wizard*

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

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

The ‘Wizard’ uses farm-specific information, and users enter their own farm-management records, their paddock soil type, local weather and one or more weed species. The Wizard has numerous weed species to choose from including annual ryegrass, barley grass, wild radish, wild oat, brome grass and silver grass in the southern states, and liverseed grass, barnyard grass, paradoxa grass, feather-top Rhodes grass, bladder ketmia, fleabane, sowthistle, sweet summer grass, cowvine and bellvine in the north.

A free download is available from: <https://www.agric.wa.gov.au/weed-seed-wizard-0>.<sup>10</sup>

[Weed Seed Wizard](#)

## 6.2 Agronomy

1. 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.
2. Conduct in-crop weed audits prior to harvest to know which weeds will be problematic the following year.
3. Ensure wheat seed is kept from a clean paddock (Figure 1).
4. Have a crop-rotation plan that considers not just crop type being grown but also what weed control options this crop system may offer, e.g. grass control with triazine-tolerant canola.

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

<sup>10</sup> GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, <http://www.grdc.com.au/Resources/IWMhub>

## **i** 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?](#)



Figure 1: Ensure wheat seed is kept from a clean paddock. (Photo: Penny Heuston)

### 6.2.1 Crop choice and sequence

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

- Rotations provide options for different weed-management tactics.
- Crop rotations can improve crop fertility 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.<sup>11</sup>

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.
- Weeds are alternate 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.<sup>12</sup>

<sup>11</sup> GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, <http://www.grdc.com.au/Resources/IWMhub>

<sup>12</sup> GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, <http://www.grdc.com.au/Resources/IWMhub>



### 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

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.



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.

A summary table of some of the key research in Australia to assess the effect of increasing crop sowing rate in the presence of weeds can be found in [IWM Section 3: Agronomy](#).



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®), introduced in 2001.

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 [CropLife Australia Limited](#) 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.

### 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 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.

## **i** More information

[GRDC: Summer fallow weed management manual](#)

[Integrated Weed Management Section 3: Agronomy](#)

## **i** GRDC Fact Sheets

[Break crop benefits. Western Region](#)

[Group A herbicides in fallow](#)

[Choosing break crops. Southern Region](#)

[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](#)

## **i** 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 weeds](#)

[Landscape and weed influence on pest and beneficial insect populations](#)

For Southern and Western Regions, further information can be found in the [Summer Fallow Weed Management Manual](#).<sup>13</sup>

### 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%.

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.<sup>14</sup>



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

<sup>13</sup> GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, <http://www.grdc.com.au/Resources/IWMhub>

<sup>14</sup> GRDC (2014) Integrated weed management manual. Integrated Weed Management Hub, GRDC, <http://www.grdc.com.au/Resources/IWMhub>

## **i** 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](#)

## **i** More information

[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 Australia](#)

[GIWA research paper: Aim for the narrowest possible row spacing WA](#)

[WeedSmart You Tube video: Diverting weed seed onto permanent tramlines](#)

## 6.3 Key weeds in Australia's cropping systems

[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 \(\*Brachiaria eruciformis\*\)](#)

[Turnip weed \(\*Rapistrum rugosum\*\)](#)

[Wild oats \(\*Avena fatua\* and \*A. ludoviciana\*\)](#)

[Wild radish \(\*Raphanus raphanistrum\*\)](#)

[Windmill grass \(\*Chloris truncata\*\)](#)

[Wireweed \(\*Polygonum aviculare\* and \*P. arenastrum\*\)](#)<sup>15</sup>

**i** Click on each weed for more information

## 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 weed-management tactics earlier in the cropping season.

Controlling weed seedset contrasts with early in-crop weed management tactics, which aim to maintain or maximise crop yield by reducing weed competition. There is minimal grain yield benefit in the current crop from seedset control tactics, because most weed

<sup>15</sup> 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/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping>

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.<sup>16</sup>

### 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 [IWM Section 4: Tactics](#)).

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.<sup>17</sup>

### 6.4.3 Crop-topping with non-selective herbicides

Crop-topping is the application of a non-selective herbicide (e.g. glyphosate or paraquat) prior to harvest when the target weed is at flowering or early grainfill. Crop-topping aims to minimise production of viable weed seed while minimising loss of crop yield.

The efficiency of the crop-topping process depends on sufficient gap in physiological maturity between crop and weed. Non-selective herbicide crop-topping registrations are largely limited to use in pulse crops and predominantly target annual ryegrass.

Crop-topping can reduce annual grass weed seedset, reducing additions to the seedbank. Reductions in seedset achieved by crop-topping can be increased if used in conjunction with selective herbicide treatments such as pre-emergent herbicides.

Crop-topping can deliver a number of benefits in addition to reducing weed seedset, for example:

- Even maturity of crops (particularly pulses) can deliver improved harvest.
- Desiccating late weed growth in seasons with late rain improves harvest, grain quality and storage.

The ideal time for crop-topping is when the annual ryegrass is just past flowering and the pulse crop is as mature as possible. More often than not some crop yield loss will occur. Product labels should be consulted for specific directions.

Crop-topping should not be performed on crops where the grain is intended for use as seed or for sprouting; the herbicide can affect seedling vigour and viability.<sup>18</sup>

See crop-topping in [IWM Section 4: Tactics](#).

## More information

[GRDC Fact Sheet: Pre-harvest herbicide use](#)

<sup>16</sup> 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>

<sup>17</sup> 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>

<sup>18</sup> 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>

### 6.4.4 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.<sup>19</sup>



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

#### More information

[IWM Section 4. Tactics](#)

[INLAND: Eliminator weed wiper](#)

[C-Dax Eliminator weed wiper](#)

### 6.4.5 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
- 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.

<sup>19</sup> 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.<sup>20</sup>

See [IWM Section 4: Tactics](#).

### 6.4.6 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.<sup>21</sup>



Figure 6: Hay cutting (left) and brown manuring (right)—two options to stop weed seedset. (Photo: A. Douglas)

#### More information

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

<sup>20</sup> 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>

<sup>21</sup> 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>



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.

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.

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.<sup>22</sup>

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.<sup>23</sup>

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<sup>24</sup>

<sup>22</sup> 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>

<sup>23</sup> 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>

<sup>24</sup> 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>

## **i** More information

[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.<sup>25</sup>

### 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](mailto:info@plantscienceconsulting.com.au), [www.plantscienceconsulting.com](http://www.plantscienceconsulting.com)

<sup>25</sup> C Preston (2014) The mechanisms of herbicide resistance. GRDC Update Papers, 5 March 2014, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/The-mechanisms-of-herbicide-resistance>



## Video

[Weed Smart](#)

## 6.6.2 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](http://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.
4. 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](http://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](http://www.grdc.com.au).
  - » Consider selective weed sprayers such as [WeedSeeker®](#) or [WEEDit®](#).

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.grdc.com.au](http://www.grdc.com.au) or [www.nga.org.au](http://www.nga.org.au).
10. 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.<sup>26</sup>

## More information

[Agronomy Australia: The extent of herbicide resistance in Tasmanian wild radish populations](#)

## 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 due to 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. Ticking 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

<sup>26</sup> 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.<sup>27</sup>

### 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.<sup>28</sup>



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

<sup>27</sup> 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>

<sup>28</sup> 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.<sup>29</sup>



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.<sup>30</sup>

### 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.

<sup>29</sup> 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>

<sup>30</sup> 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.<sup>31</sup>



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)<sup>32</sup>

### 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.<sup>33</sup> Planned cultivation can also be used as a non-herbicide component of a double-knock system (see [IWM Section 4: Tactics](#)).



Video

[Strategic tillage](#)

<sup>31</sup> 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>

<sup>32</sup> 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>

<sup>33</sup> 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

1. 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
2. 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.
4. 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.



## More information

[GRDC Fact Sheets: Strategic tillage](#)

## Video

[Herbicide Innovation Partnership](#)

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.<sup>34</sup>

### 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 pre-emergent chemistries.

Hence, we need to look after what is available for as long as possible.<sup>35</sup>

Further information on registered chemicals can be obtained from [APVMA](#) and [CropLife Australia](#), and [Regional weed control references](#).

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

Since its release in the late 1970s, glyphosate has become the most widely used herbicide 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 [Australian Glyphosate Sustainability Working Group](#) provides up-to-date information on glyphosate and paraquat resistance.

<sup>34</sup> 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>

<sup>35</sup> 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>

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.<sup>36</sup>

### *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.<sup>37</sup>

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 crus-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.)

<sup>36</sup> 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>

<sup>37</sup> 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>

## More information

[GRDC: Summer fallow weed management](#)

## Video

[Double knock timing](#)

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 or more 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.<sup>38</sup>

#### 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. Pre-emergent herbicides are particularly useful at stopping early weed competition, especially if high weed densities are expected.
- Crop or pasture type. What is registered, how competitive is the crop, and which post-emergent options exist?
- Soil condition. Cloddy soil surfaces, large amounts of stubble or an excess of ash from stubble burning can affect the performance of some pre-emergent herbicides.

<sup>38</sup> 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>

### More information

[GRDC: Summer fallow weed management](#)

Less soluble herbicides such as simazine need to be mixed with the topsoil for best results. The more mobile herbicides such as sulfonyleureas 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 2):

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

## More information

[IWM Section 4: Tactics](#)

Table 2: Soil attributes that contribute to herbicide availability

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

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

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

Crop safety is also an important issue when using pre-emergent herbicides. Crop tolerance of several pre-emergent herbicides (i.e. trifluralin, pyroxasulfone, prosulfocarb) is often related to spatial separation of the young crop from the herbicide. This, in turn, is related to the solubility and potential movement in the soil of the herbicide, the crop establishment process, the level of soil displacement over the crop row, follow-up rainfall and the physical nature of the seed furrow.<sup>39</sup>

<sup>39</sup> 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>

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

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

### Selective post-emergent herbicides

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

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

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

Many new selective post-emergent herbicides have been released in recent years; however, all of them have been from known MOA groups. No new post-emergent herbicides from new MOA groups are likely to be released in the near future.

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

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

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

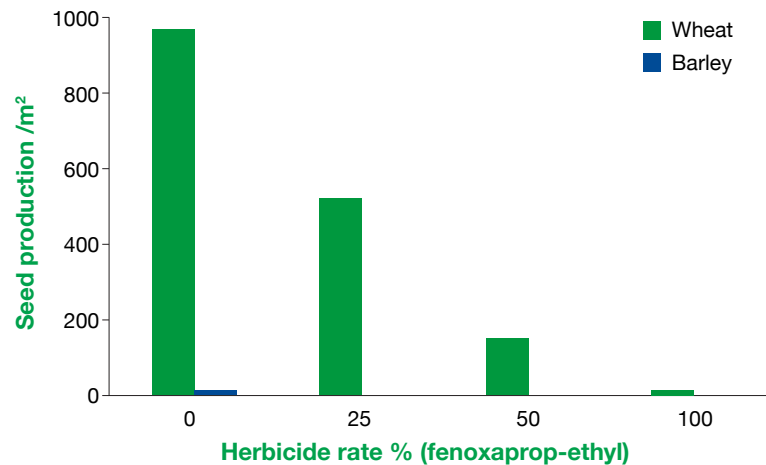


Figure 12: Effect of crop type and herbicide rate on paradoxa grass seed production. (Source: Walker et al. 1998)

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

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

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

To get the best performance from the herbicide being applied, use the adjuvant recommended on the herbicide label. Because plants have different leaf surfaces, an adjuvant may be needed to assist with herbicide uptake and leaf coverage. Some adjuvants can also increase performance by lowering the pH, water hardness, compatibility, rain-fastness or drift. 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 4). Seedbank capture and management tactics work similarly to help drive the weed seedbank down.

Table 4: Effect of annual applications of different herbicide treatments on wild oat seedbank numbers after 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 <sup>40</sup>

### 6.8.3 Spot spraying, chipping, hand roguing and wiper technologies

When weed numbers are low or when still contained in patches, hand weeding, spot spraying and other methods, including selective crop destruction, can be used to stop weed seedset and seedbank replenishment.

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.

<sup>40</sup> 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>

## **i** More information

[Tactic 2.4 of IWM Section 4: Tactics](#)

## **i** More information

[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](#)

- 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.<sup>41</sup>

### 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 Grains 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 larger 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.<sup>42</sup>

### 6.8.5 Biological control

Biological control for the management of weeds uses the weed's natural enemies (biological control agents). These include herbivores, such as insects and sheep, where there is direct consumption of the weed. Natural enemies also include microorganisms such as bacteria, fungi and viruses, which can cause disease, reduce weed vigour and competitiveness relative to the crop, and decay the weed seed in the seedbank. Other plants can also be included here, where they release substances that suppress weed growth—this is known as allelopathy.<sup>43</sup>

## 6.9 Harvest weed-seed control

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 Wheat South Section 12. Harvest](#).

<sup>41</sup> 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>

<sup>42</sup> 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>

<sup>43</sup> 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>



## **i** GRDC Fact Sheets

[In-crop herbicide use \(Northern, Southern and Western Regions\)](#)

[Practical tips for spraying \(Northern, Southern and Western Regions\)](#)

[Pre-emergent herbicides \(Northern, Southern and Western Regions\)](#)

[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 \(Northern, Southern and Western Regions\)](#)

## **i** GRDC Update Papers

[Achieving good pre-emergent spray results](#)

[Getting the right mix](#)

[Hardseeded annual legumes](#)

[Herbicide efficacy in no-till farming systems in southern NSW](#)

## 6.10 Other non-chemical weed control

Crop rotation, especially with summer crops, 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.<sup>44</sup>

The use of rotations that include both broadleaf and cereal crops may allow an increased range of chemicals—say three to five MOAs—or non-chemical tactics such as cultivation or grazing. For the management of wild oats, the inclusion of a strategic summer crop such as sorghum means two winter fallows, with glyphosate an option for fallow weed control. Grazing and/or cultivation are alternative, non-chemical options.

Where continuous summer cropping has led to development of Group M-resistant annual ryegrass, a winter crop could be included in the rotation and a Group A, B, C, D, J or K herbicide used instead, along with crop competition and potential harvest-management tactics.

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.<sup>45</sup>

## 6.11 Crop competition

A recent field trial near Warwick, Queensland, showed that fleabane density and seed production could be substantially manipulated by using crop competition in the absence of herbicides. The site received considerable rainfall during the 2010 crop-growing season, which promoted fleabane emergence and good early crop growth.

For wheat, there were trends to lower fleabane numbers with increasing crop population and narrower row spacing (Figure 13). On average, weed density decreased by 26% as crop population increased from 50 to 100 plants/m<sup>2</sup>, and by 44% as row spacing decreased from 50 to 25 cm. These treatments also had impacts on seed production, as indicated by seed head counts (Figure 14). Row spacing tended to have a much greater effect than crop population. The data indicate that durum wheat responded in a manner similar to bread wheat.<sup>46</sup>

<sup>44</sup> DAF Qld (2012) Wheat—planting information. Department of Agriculture and Fisheries, Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/planting-information>

<sup>45</sup> GRDC (2012) Cropping with herbicide resistance. Herbicide resistance Fact Sheet. GRDC, <http://www.grdc.com.au/Media-Centre/Hot-Topics/Herbicide-Resistance>

<sup>46</sup> GRDC (2011) Keeping on top of fleabane—in-crop strategies, the role and impact of residual herbicides, crop competition and double-knock. GRDC Update Papers, 20 April 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/04/Keeping-on-top-of-fleabane-incrop-strategies-the-role-and-impact-of-residual-herbicides-crop-competition-and-doubleknock>

## **i** GRDC Update Papers

[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](#)

[NGA chickpea herbicide trials 2014](#)

[Pre-emergent herbicides and seeding system interactions](#)

[Protecting glyphosate in summer fallows – mixes with pre-emergent herbicides and double knocking trials](#)

[Seeding systems and pre-emergence herbicides](#)

[The strategic use of tillage in conservation farming](#)

## **▶** GRDC Videos

[Advances in weed management: Spray application in summer fallows](#)

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

[Crop competition for weed management – narrow row spacings](#)

[Double knock applications – a grower's experience](#)

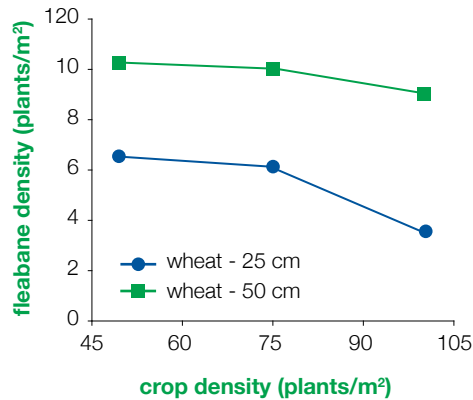


Figure 13: Fleabane density (no. of plants/m<sup>2</sup>) in wheat of different row spacing and plant density. (DAF Qld)

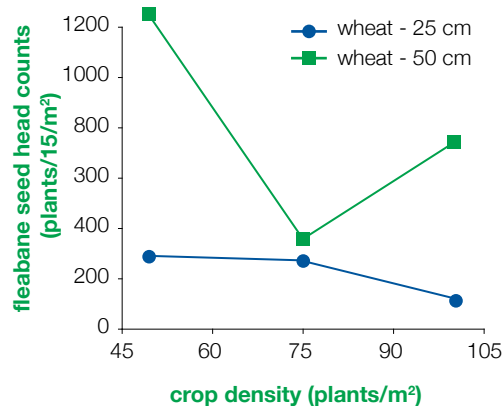


Figure 14: Average fleabane seedhead counts (no. of plants/15 m<sup>2</sup>) in wheat across different row spacing and plant density. (DAF Qld)

For information on sowing rates and plant population, see [GrowNotes Wheat South Section 3. Planting](#).

Northern Grower Alliance trials show that the use of a disc planter for incorporation by sowing (IBS) of residual herbicides resulted in significantly reduced wheat emergence for all four herbicides evaluated. The disc planter set-up actually increased the risk of crop damage. These results reinforce the need to use only narrow-point tines when using residual herbicides with IBS recommendations.<sup>47</sup>

## 6.12 Herbicides explained

### 6.12.1 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).

<sup>47</sup> GRDC (2014) Pre-emergent herbicides: part of the solution but much still to learn. GRDC Update Papers, 5 March 2014, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn>

## GRDC Videos

[Double knock applications—double knock strategies for resistant weed populations](#)

[Double knock applications—target weed species and application strategy](#)

[GCTV10: Double knock timing](#)

[GCTV11: Strategic tillage, does no-till mean never till?](#)

[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](#)

## Videos

[SANTFA: Summer weed control](#)

[WeedSmart: Understanding pre-emergent herbicides](#)

[WeedSmart: When is it worth rotating from Select to Factor?](#)

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.

### 6.12.2 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.<sup>48</sup>

## 6.13 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<sup>49</sup>

Choice of herbicides for weed control in wheat 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).

### 6.13.1 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.

### 6.13.2 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

<sup>48</sup> GRDC. Integrated weed management, Section 4: Tactics for managing weed populations. GRDC/CRC for Australian Weed Management, <http://www.grdc.com.au/-/media/A4C48127FF8A4B0CA7DFD67547A5B716.pdf>

<sup>49</sup> GRDC (2014) Understanding pre-emergent cereal herbicides. GRDC Update Papers 4 March 2014, <https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides>

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 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.

2. 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 pre-emergent herbicides to gain a competitive advantage.
3. Soil condition. Soil preparation is a critical first step in the effective use of pre-emergent 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).
4. 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.<sup>50</sup>

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 wheat will depend on the specific weed species and the crop situation. Consult with your agronomist for further details.

### 6.13.3 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.

<sup>50</sup> GRDC. Integrated weed management, Section 4: Tactics for managing weed populations. GRDC/CRC for Australian Weed Management, <http://www.grdc.com.au/-/media/A4C48127FF8A4B0CA7DFD67547A5B716.pdf>

## More information

[GRDC Integrated Weed Management Hub](#)

[NGA: Project reports – weeds](#)

[GRDC: Grain Orana Alliance](#)

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 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.<sup>51</sup>

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 5 all have some residual activity or planting restrictions.

Table 5: Active constituent by herbicide group (may not include all current herbicides)

Herbicide group	Active constituent
Group B. Sulfonylureas	Chlorsulfuron (Glean <sup>®</sup> ), iodosulfuron (Hussar <sup>®</sup> ), mesosulfuron (Atlantis <sup>®</sup> ), metsulfuron (Ally <sup>®</sup> ), triasulfuron (Logran <sup>®</sup> )
Group B. Imidazolinones	Imazamox (Raptor <sup>®</sup> ), imazapic (Flame <sup>®</sup> ), imazapyr (Arsenal <sup>®</sup> )
Group B. Triazolopyrimidines (sulfonamides)	Florasulam (Conclude <sup>®</sup> )
Group C. Triazines	Atrazine, simazine
Group C. Triazinones	Metribuzin (Sencor <sup>®</sup> )
Group C. Ureas	Diuron
Group D. Dinitroanilines	Pendimethalin (Stomp <sup>®</sup> ), trifluralin
Group H. Pyrazoles	Pyrasulfotole (Precept <sup>®</sup> )
Group H. Isoxazoles	Isoxaflutole (Balance <sup>®</sup> )
Group I. Phenoxy carboxylic acids	2,4-Ds
Group I. Benzoic acids	Dicamba
Group I. Pyridine carboxylic acids	Clopyralid (Lontrel <sup>®</sup> )
Group K. Chloroacetamides	Metolachlor
Group K. Isoxazoline	Pyroxasulfone (Sakura <sup>®</sup> )

### 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 re-cropping periods on the product label for each paddock.<sup>52</sup>

### 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.

<sup>51</sup> Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. DEDJTR Victoria, <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>

<sup>52</sup> Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. DEDJTR Victoria, <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>

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 (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.<sup>53</sup>

### 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 ≥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 US 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.

<sup>53</sup> Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, DEDJTR Victoria, <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.<sup>54</sup>

### 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.<sup>55</sup>

## More information

[Australian Pesticides and Veterinary Medicines Authority](#)

## 6.14 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 [Syngenta Quick-Test](#)).
- 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.

<sup>54</sup> Dual Gold® herbicide

<sup>55</sup> Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, DEDJTR Victoria, <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 [GrowNotes Wheat South Section 4. Plant growth and physiology](#).

### 6.14.1 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.

### 6.14.2 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

## 6.15 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 15). The units have their own light source so can be used day or night.



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 15: Selective sprayer technologies use optical sensors to turn on spray nozzles only when green weeds are detected. (Photo: CropOptics)

### 6.15.1 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.

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.<sup>56</sup>

For more information on fallow weed control, see [GrowNotes Wheat South Section 1. Planning and paddock preparation](#).

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.

<sup>56</sup> 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>

## 6.16 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

### More information

[IWM section 4: Tactics](#)

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

### 6.16.1 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 have shown 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.<sup>57</sup>

### More information

[IWM section 4: Tactics](#)

### 6.16.2 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 16). 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.<sup>58</sup>

### Video

[Herbicide resistance](#)

<sup>57</sup> 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>

<sup>58</sup> 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>



Figure 16: Flaxleaf fleabane along this fence will easily spread into neighbouring fields. (Photo: A. Storrie)

### **i** More information

[IWM section 4: Tactics](#)

### **i** More information

[IWM section 4: Tactics](#)

### **i** More information

[IWM section 4: Tactics](#)

#### 6.16.3 Clean farm machinery and vehicles

Machinery and vehicles are major sources for the introduction of new weeds. Earth-moving 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.<sup>59</sup>

#### 6.16.4 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.<sup>60</sup>

#### 6.16.5 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 17).

Effective monitoring to identify new weed incursions and patches is needed. Hand-roguing a few plants every year can help when weed numbers are very low, even on very large properties.<sup>61</sup>

<sup>59</sup> 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>

<sup>60</sup> 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>

<sup>61</sup> 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>

## More information

[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](#)



*Figure 17: 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. Storrie)*

## GRDC Videos

[GRDC webinar on managing weeds on fencelines](#)

[Weed seed bank destruction – farm hygiene and weed management](#)

## SECTION 7

# Insect and other pest control

Insects are not usually a major problem in winter wheat but sometimes they build up to an extent that control may be warranted. For current chemical control options, refer to the [Pest Genie](#) or [Australian Pesticides and Veterinary Medical Authority \(APVMA\)](#) websites.<sup>1</sup>

Where chemical control is warranted, farmers are increasingly being strategic in their management and avoiding broad-spectrum insecticides where possible. Thresholds and potential economic damage are carefully considered.

## Agronomist's view

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.), cutworms, aphids, slugs, snails, earwigs, millipedes, slaters, army worms, pasture webworm, pasture cockchafers, and grass antherids, lucerne flea (*Sminthurus viridis*), leaf hoppers, slugs, snails, millipedes, slaters and locusts (Tables 1 and 2). Mice may also cause damage.

Table 1: Pests that pose a risk to cereal crops<sup>2</sup>

High risk	Moderate risk	Low risk
<i>Soil insects, slug and snails</i>		
Some crop rotations increase the likelihood of soil insects: cereal sown into a long-term pasture phase high stubble loads above-average rainfall over summer–autumn History of soil insects, slugs and snails Summer volunteers and <i>Brassica</i> weeds will increase slug and snail numbers Cold, wet establishment conditions expose crops to slugs and snails	Information on pest numbers prior to sowing from soil sampling, trapping and/or baiting will inform management Implementation of integrated slug management strategy (burning stubble, cultivation, baiting) where there is a history of slugs Increased sowing rate to compensate for seedling loss caused by establishment pests	Slugs and snails are rare on sandy soils
<i>Earth mites</i>		
Cereals adjacent to long-term pastures may get mite movement into crop edges Dry or cool, wet conditions that slow crop growth increase crop susceptibility to damage History of high mite pressure	Leaf curl mite populations (transmitters of <i>Wheat streak mosaic virus</i> ) can be increased by grazing and mild wet summers	Seed dressings provide some protection, except under extreme pest pressure

<sup>1</sup> 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>

<sup>2</sup> NIPI. Winter cereals. NIPI IPM guidelines, <http://ipmguidelinesforgrains.com.au/crops/winter-cereals/>

High risk	Moderate risk	Low risk
<i>Aphids</i>		
Higher rainfall areas where grass weeds are present prior to sowing—higher risk of <i>Barley yellow dwarf virus</i> transmission by aphids	Wet autumn and spring promote the growth of weed hosts; when weed hosts dry off, aphids move into crops	Low-rainfall areas—lower risk of BYDV infection
Wet summer and autumn promoting survival of aphids on weed and volunteer hosts	Planting into standing stubble can deter aphids landing	High beneficial activity (not effective for management of virus transmission)
	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	
<i>Armyworm</i>		
Large larvae present when the crop is at late ripening stage	High beneficial insect activity (particularly parasitoids)	No armyworm present at vegetative and grain-filling stages
	Rapid crop dry-down	

Table 2: Incidence of pests of winter cereals<sup>3</sup>

Present, present in crop but generally not damaging; Damaging, crop susceptible to damage and loss; snails are also a grain contaminant at harvest

	Crop stage			
	Emergence	Vegetative	Flowering	Grainfill
<a href="#">Wireworms</a>	Damaging	Present		
<a href="#">Cutworm</a>	Damaging			
<a href="#">Black headed cockchafer</a>	Damaging	Present		
<a href="#">Earth mites</a>	Damaging	Present		
<a href="#">Slugs, snails</a>	Damaging			
<a href="#">Brown wheat mite</a>		Damaging		
<a href="#">Aphids</a>	Present	Damaging	Present	Present
<a href="#">Armyworm</a>		Present	Present	Damaging
<a href="#">Helicoverpa armigera</a>				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.

## More information

[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 antheilids](#)

[GRDC Ute Guides: Insects](#)

[GRDC Update Papers: Insect pests—resistance, virus vectors and lessons from 2014](#)

<sup>3</sup> NIPI (2014) Winter cereals. NIPI IPM guidelines, <http://ipmguidelinesforgrains.com.au/crops/winter-cereals/>

Table 3: Crop damage pest identification key for the Southern Region—cereals<sup>4</sup>

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 antheiid*
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
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.	Sandgroppers**
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 wiggly or zigzag lines. Yellow to green, 3 mm long wedge-shaped sucking insects that jump sideways when disturbed.	Leafhoppers

\* Relevant in S.E. Australia only

<sup>4</sup> 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>

Table 4: Establishment pests of the Southern Region—risk assessment and management <sup>5</sup>

Pre-season	Pre-sowing	Emergence	Crop establishment
<i>Earth mites and lucerne flea</i>			
<p>Assess risk. High risk when:</p> <ul style="list-style-type: none"> <li>history of high mite pressure</li> <li>pasture rotating into crop</li> <li>susceptible crop being planted (e.g. canola, pasture, lucerne)</li> <li>seasonal forecast for dry or cool, wet conditions that slow crop growth</li> </ul> <p>If risk is high:</p> <ul style="list-style-type: none"> <li>ensure accurate identification</li> <li>use TIMERITE® (redlegged earth mites only)</li> <li>heavily graze pastures in early-mid spring</li> </ul>	<p>If high risk:</p> <ul style="list-style-type: none"> <li>use an insecticide seed dressing on susceptible crops</li> <li>plan to monitor more frequently until crop establishment</li> <li>use higher sowing rate to compensate for seedling loss</li> <li>consider scheduling a post-emergent insecticide treatment</li> </ul> <p>If low risk:</p> <ul style="list-style-type: none"> <li>avoid insecticide seed dressings (esp. cereal and pulse crops) and plan to monitor until crop establishment</li> </ul>	<p>Monitor susceptible crops through to establishment using direct visual searches. Be aware of edge effects; mites move in from weeds around paddock edges</p> <p>If spraying:</p> <ul style="list-style-type: none"> <li>ensure accurate identification of species before deciding on chemical</li> <li>consider border sprays (mites) and 'spot' sprays (lucerne flea)</li> <li>spray prior to winter egg production to suppress populations and reduce risk in the following season</li> </ul>	<p>As the crop grows, it becomes less susceptible unless growth is slowed by dry or cool, wet conditions</p>
<i>Slugs</i>			
<p>Assess risk. High risk when:</p> <ul style="list-style-type: none"> <li>high stubble load</li> <li>annual average rainfall &gt;450 mm</li> <li>history of slug infestations</li> <li>canola being planted</li> <li>summer rainfall</li> <li>heavy clay soils</li> </ul>	<p>If high risk:</p> <ul style="list-style-type: none"> <li>burn stubbles</li> <li>cultivate worst areas</li> <li>remove weeds in paddocks/along fencelines at least 8 weeks before sowing</li> <li>deploy shelter traps before sowing</li> <li>sow early to get crop established prior to cold conditions</li> <li>use soil compaction at sowing (e.g. press-wheels)</li> <li>bait at/after sowing prior to emergence</li> </ul>	<p>Assess risk. High risk under cold conditions and with slow plant growth.</p> <p>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</p>	<p>As the crop grows, it becomes less susceptible unless growth is slowed by cool conditions. Resowing may be required if plant stands are unsatisfactory</p>
<i>False wireworm and true wireworm</i>			
<p>Assess risk. High risk when:</p> <ul style="list-style-type: none"> <li>history of wireworm pressure</li> <li>soils high in organic matter</li> <li>high stubble and summer-autumn litter cover</li> </ul>	<p>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:</p> <ul style="list-style-type: none"> <li>reassess crop choice or timing of sowing</li> <li>consider an insecticide seed dressing (particularly fipronil) or in-furrow treatment</li> <li>use soil compaction at sowing (e.g. press-wheels)</li> <li>consider higher sowing rate to compensate for seedling loss</li> </ul>	<p>Limited options for control once crop is sown. Consider resowing severely affected areas of crop</p>	<p>Damage to established crops is rare</p>

<sup>5</sup> NIPI (2014) Establishment pests—Southern Region. 'Best bet' IPM strategy. NIPI IPM Workshops, [http://ipmworkshops.com.au/wp-content/uploads/BestBet\\_EstablishmentSouth2014.pdf](http://ipmworkshops.com.au/wp-content/uploads/BestBet_EstablishmentSouth2014.pdf)



Pre-season	Pre-sowing	Emergence	Crop establishment
<b>Scarabs</b>			
Assess risk. High risk when: <ul style="list-style-type: none"> <li>sowing crop into pasture, esp. with a high clover content</li> <li>previous history of scarab damage to crop in that field</li> <li>wetter than average seasons</li> <li>minimum/no tillage</li> <li>Under high pressure:               <ul style="list-style-type: none"> <li>spray African black beetle adults in spring</li> <li>avoid overgrazing pastures</li> </ul> </li> </ul>	Dig soil within paddock to determine incidence of scarab larvae.  If high risk: <ul style="list-style-type: none"> <li>cultivate land</li> <li>avoid sowing grass pastures</li> <li>use soil compaction at sowing (e.g. press-wheels)</li> <li>consider higher sowing rate to compensate for seedling loss</li> </ul>	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
<b>Others—e.g. earwigs, slater, millipedes, weevils</b>			
Assess risk. High risk when: <ul style="list-style-type: none"> <li>history of high pest pressure</li> <li>minimum/no tillage</li> <li>high stubble load</li> <li>heavier soils</li> <li>Monitor in spring using shelter traps, direct searches and/or pitfall traps</li> </ul>	If high risk: <ul style="list-style-type: none"> <li>burn stubbles</li> <li>cultivate worst areas</li> <li>use cracked wheat baits</li> <li>avoid sowing canola</li> </ul>	Monitor susceptible crops through to establishment. Directly search at night to confirm pest species as the cause of seedling loss (Note: large numbers of these pests can be found in paddocks without causing crop damage)	Damage to established crops is rare

## More information

[NIPI IPM Workshops: Establishment pests—Southern Region](#)

[NIPI IPM Workshops: Decision making for insect management in grain crops](#)

## 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.<sup>6</sup>

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), 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.

<sup>6</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf)

- *Helicoverpa armigera* has historically had high resistance to pyrethroids, and the inclusion of nuclear polyhedrosis virus (NPV) is effective where mixed populations of armyworm and *Helicoverpa* occur in maturing winter cereals.<sup>7</sup>

## 7.2 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.<sup>8</sup>



Figure 1: Adult lucerne flea (*Sminthurus viridis*). (Photo: cesar)

### 7.2.1 Description

Adult lucerne fleas are globular, wingless insects, 2–3 mm long with green, brown and yellow markings (Figure 1). They appear yellow-green to the naked eye, although their globular abdomens are often a mottled pattern of darker pigments. They make jumping movements when disturbed. Nymphs resemble the adults except in size.<sup>9</sup>

### 7.2.2 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

<sup>7</sup> NIPI (2014) Winter cereals. NIPI IPM guidelines, <http://ipmguidelinesforgrains.com.au/crops/winter-cereals/>

<sup>8</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf)

<sup>9</sup> CropPro. Lucerne flea. Pests in canola. CropPro, [http://www.croppro.com.au/cb\\_pages/pests\\_in\\_canola\\_-\\_in\\_crop.php?category\\_id=2374](http://www.croppro.com.au/cb_pages/pests_in_canola_-_in_crop.php?category_id=2374)

they follow a weed-infested crop or a pasture in which the lucerne flea has not been controlled.

### 7.2.3 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.

### 7.2.4 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.<sup>10</sup>

**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.<sup>11</sup>

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 overwintering 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.

## 7.3 Earth mites

A good mite-control program starts with a population-reduction treatment the previous spring (see Table 4 above). Learn to identify these species of mites to ensure that the correct insecticide and rate is applied to the correct pest.

See [Australian Pesticides and Veterinary Medicines Authority](#) for up-to-date on-label information.

### 7.3.1 Blue oat mite (*Penthaleus* spp.)

Blue oat mites (Figure 2) 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 5). 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.

<sup>10</sup> CropPro. Lucerne flea. Pests in canola. CropPro, [http://www.croppro.com.au/cb\\_pages/pests\\_in\\_canola\\_-\\_in\\_crop.php?category\\_id=2374](http://www.croppro.com.au/cb_pages/pests_in_canola_-_in_crop.php?category_id=2374)

<sup>11</sup> 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/>

## 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 \(section 4, pp. 63–64\)](#)

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 practiced. 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.<sup>12</sup>

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.



Figure 2: Blue oat mite (*Penthaleus* sp.). (Photo: A Weeks, cesar)

Table 5: Management summary of blue oat mite<sup>13</sup>

Scientific name	<i>Penthaleus major</i> , <i>P. falcatus</i> , <i>P. tectus</i>
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	<a href="#">Brown wheat mite</a> , <a href="#">redlegged earth mite</a>
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. In canola, leaves are mottled or whitened in appearance
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 <a href="#">Pest Genie</a> or <a href="#">APVMA</a>
Natural enemies	Thrips and ladybirds

Blue oat mites are often confused with redlegged earth mites. There are three recognised pest species of blue oat mites in Australia: *Penthaleus major*, *P. falcatus*, and *P. tectus*. Accurate identification of the species requires examination by an

<sup>12</sup> 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>

<sup>13</sup> DAF Qld (2010) Blue oat mite. 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>

entomologist. The species vary with respect to their geographical distribution in Australia.<sup>14</sup>

### 7.3.2 Redlegged earth mites (*Halotydeus destructor*)

Characteristics and management of redlegged earth mites (Figure 3) are summarised in Table 6.



Figure 3: Adult redlegged earth mites (*Halotydeus destructor*). (Photo: cesar)

Table 6: Management summary of redlegged earth mite

Scientific name	<i>Halotydeus destructor</i>
Description	Adults are 1 mm long and have eight legs. Adults and nymphs have a black, somewhat flattened body and red legs
Similar species	Similar in appearance to blue oat mite; however, <a href="#">blue oat mite</a> can be distinguished by a small oval red area in the middle of the back
Distribution	Originated in South Africa, now found in New Zealand and Australia. The redlegged earth mite is widely distributed in winter-rainfall-dominant regions of southern Australia
Pest status	Major, widespread, regular, in southern Australia
Crops attacked	Damages all field crops and pastures, especially at seedling stage. A major pest of legume pastures and canola
Damage	Adults and nymphs feeding cause a silver or white discoloration of leaves and distortion of leaf shape. Affected seedlings can die. Seedlings can be killed before emergence. There is also reduced production and quality of older green plants during the growing season and reduced seed yield of legumes in spring
Risk period	Autumn to spring, especially at germination
Life cycle	<p>On winter-rainfall pastures: The redlegged earth mite is active in the cool, wet months from May to November. They hatch in autumn at the break of the season, from overwintering eggs that have been in a state of arrested development (diapause) since the end of the previous spring. Hatching is triggered by a significant rainfall event combined with a period of 7–10 days where the mean daily maximum temperature is &lt;21°C</p> <p>Eggs hatch into six-legged larvae and then develop through three nymphal stages into adults. Nymphs and adults have eight legs. During winter, the redlegged earth mite passes through three generations on average, each lasting about 8 weeks. When conditions are favourable, numbers can increase rapidly, with peaks in autumn and/or spring</p>

<sup>14</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf)

## More information

GRDC: Insect ID: the Ute Guide tablet edition

Monitoring	Monitor pastures regularly from the time of first emergence of seedlings. Approach quietly as mites will disperse quickly if disturbed. If mites are not found on the plants, look carefully at the soil surface. A hand lens will be required to detect newly hatched larvae and young nymphs
Action level	Any sign of mite activity or damage at germination warrants control. At other times of the season, feeding damage to >20% of the leaf area may warrant control
Control	<p>Chemical control: Treating seed with systemic insecticide before sowing pastures protects seedlings from attack. Chemical sprays do not kill mite eggs, so it is important to time spraying for when most mites have emerged. Spraying should be timed for autumn or spring. In autumn, chemicals should be applied after the break of season, and after all of the overwintering eggs have hatched but before adult mites start laying eggs. For current chemical control options see <a href="#">APVMA</a></p> <p>Cultural control: Heavy grazing in winter and spring reduces mite populations. Control of broadleaf weeds in summer can reduce mite populations in autumn.</p> <p>Natural enemies: A predatory mite, <i>Anystis wallacei</i>, was imported from France to Australia in 1965 for biological control and has established at some sites, where it has caused significant mortality of redlegged earth mites. Its effectiveness is limited by its slow dispersal</p>

### *TIMERITE® for management of redlegged earth mite*

TIMERITE® is an information package that provides individual farmers with the optimum spray date on their farm to control redlegged earth mites during spring. Developed by CSIRO and Australian Wool Innovation, TIMERITE® predicts the optimum date in spring to control redlegged earth mites, just after they have ceased laying normal winter eggs on pasture and just before diapause. (Diapause is when adult redlegged earth mites produce eggs that are retained in the body of the adult female and are therefore protected from the effects of insecticide applications.) The single, strategic spray has a two-fold effect: controlling redlegged earth mites in spring and decreasing the summer population that emerges in the following autumn. The package may form part of an integrated management strategy to control redlegged earth mites.

Close attention should be paid to individual pesticide labels when controlling earth mites. Application rates vary with situations, such as bare earth or post-emergence of crops or pasture. Correct identification of earth mite species is essential. Registrations sometimes include redlegged earth mites only, not blue oat mites or *Bryobia* mites. Application rates may vary with earth mite species. See [APVMA](#).

This strategic approach has little effect on non-target invertebrates, both pest and beneficial, during the following autumn. Farmers need to identify geographically the location to be sprayed. This can be done by a local feature, such as town or mountain, or the longitude and latitude of the area. This information is used to find the optimum date from the package. The spray date for each farm is the same date each year. For information, phone Australian Wool Innovation toll free on 1800 070 099 or visit the website: [AWI: TIMERITE](#).<sup>15</sup>

### 7.3.3 *Balaustium* mites (*Balaustium medicagoense*)

#### Description

*Balaustium* mites grow to 2 mm in length and have a rounded, red-brown body with eight red-orange legs (Figure 4). Adults are covered with short, stout hairs. They are slow moving and have distinctive, pad-like structures on their forelegs. The *Balaustium* mite is commonly confused with *Bryobia* mite, and sometimes with blue oat mite and redlegged earth mite. However, *Balaustium* mites are generally twice as large as other mites when adults. Newly hatched mites are bright orange with six legs and are only 0.2 mm in length.

<sup>15</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf)



Figure 4: *Balaustium mites* (*Balaustium medicagoense*). (Photo: cesar)

### Seasonal development

Little is known about the biology of *Balaustium* mites. They usually have two generations per season and are unlikely to require cold temperatures to stimulate egg hatching like other species.

### Impact

*Balaustium* mites are unusual in that they not only feed on plants but also prey upon other small invertebrates. They have been reported to feed on several different groups, including various Collembola species and other mites. *Balaustium* mites were originally thought to be a beneficial predator with some reports suggesting that they provided localised control of redlegged earth mites. Only recently have *Balaustium* mites been confirmed to feed on plant material.

Canola, lupins and cereals are the most susceptible crops, particularly at the seedling stage. Some broadleaf weeds are alternative hosts. Typical damage to cereals, grasses and pulses is 'silvering' or 'whitening' of the attacked foliage, similar in appearance to damage caused by redlegged earth mites and blue oat mites. However, *Balaustium* mite damage differs in that they tend to attack the leaf edges and tips of plants. Adult mites are likely to be responsible for the majority of feeding damage to plants.

*Balaustium* mites feed on plants by using their adapted mouthparts to probe leaf tissue and suck up sap. In most situations, they cause little damage; however, when numbers are high and plants are already stressed from other environmental conditions, significant damage to crops can occur.

### Management

There are very few effective biological control options. Early control of summer and autumn weeds within and around paddocks, especially cape weed and grasses, will help to control populations. *Balaustium* mites have a high natural tolerance to chemicals and they will typically survive pesticide applications aimed at other mite pests.<sup>16</sup>

### Distribution

*Balaustium* mites are widespread throughout most agricultural regions in southern Australia with a Mediterranean-type climate (Figure 5). They are found in Victoria, New South Wales and South Australia. They are generally restricted to coastal areas and do not occur far inland or in the drier Mallee areas of Victoria and South Australia.

<sup>16</sup> GRDC (2012) Crop mites. Back Pocket Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2012/06/GRDC-Crop-Mites-Back-Pocket-Guide>

*Balaustium* mites have been found in Tasmania; however, no systematic sampling has been conducted and the distribution across the state remains unknown.

Similar to other pest mites, long-range dispersal is thought to occur via the movement of eggs in soil adhering to livestock and farm machinery or through transportation of plant material. Movement may also occur if overwintering eggs are moved by summer winds.

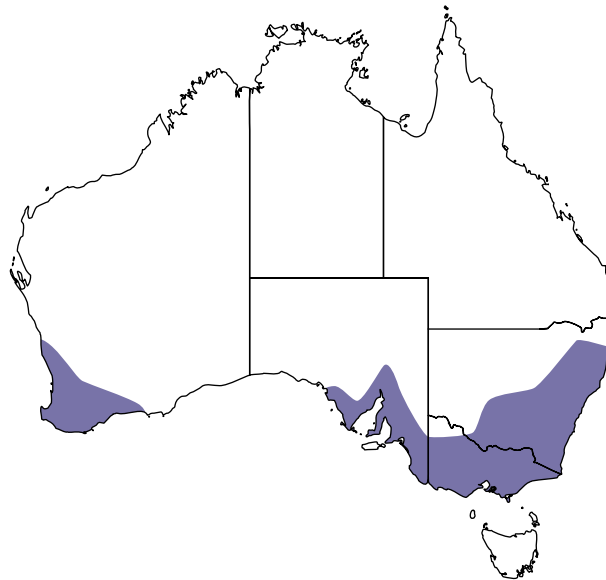


Figure 5: Distribution of *Balaustium* mite in southern Australia. (Source: Agriculture Victoria)

### Monitoring

The impact of mite damage is increased when plants are under stress from adverse conditions such as prolonged dry weather or waterlogged soils. Ideal conditions for seedling growth enable plants to tolerate higher numbers of *Balaustium* mites. Carefully inspect susceptible pastures and crops from autumn to spring for the presence of mites and evidence of damage. It is especially important to inspect crops regularly in the first 3–5 weeks after sowing.

Crops sown into paddocks that were in pasture the previous year should be regularly inspected. Weeds present in paddocks prior to cropping should also be checked for the presence and abundance of *Balaustium* mites. Mites are best detected feeding on the leaves, especially on or near the tips, during the warmest part of the day. They are difficult to find when conditions are cold and/or wet.

One of the most effective methods to sample mites is by using a D-Vac, which is based on the vacuum principle, much like a domestic vacuum cleaner. Typically, a standard, petrol-powered garden blower/vacuum machine is used. A sieve is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface.<sup>17</sup>

### 7.3.4 *Bryobia* mites

#### Description

*Bryobia* mites (also referred to as clover mites) are smaller than other commonly occurring pest mites, reaching ~0.75 mm in length as adults. They have an oval, flattened dorsal body that is dark grey, pale orange or olive and have eight pale-orange legs (Figure 6). The front pair of legs is much larger, about 1.5 times their body length. Nymphs are small with bright-red bodies and pale legs.<sup>18</sup>

<sup>17</sup> Agriculture Victoria (2010) *Balaustium* mite. AG1413. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/balaustium-mite>

<sup>18</sup> GRDC (2012) Crop mites. Back Pocket Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2012/06/GRDC-Crop-Mites-Back-Pocket-Guide>



The egg of the *Bryobia* mite is minute, globular and red. It can be distinguished from European red mite eggs by its smooth appearance and lack of a spike. The nymph looks like the adult but is smaller.<sup>19</sup>

Many species of *Bryobia* mites are found in grain crops in Australia. They are found in high numbers in the warmer months from spring through to autumn. *Bryobia* mites prefer broadleaf plants such as canola, lupins, vetch, lucerne and clover, but they will also attack cereals.<sup>20</sup>



Figure 6: Adult *Bryobia* mite. (Photo: cesar)

### Management

There are no known biological control options. Crops that follow clover-dominant pastures are most at risk, and should be monitored carefully. Early control of summer and autumn weeds within and around paddocks, especially broadleaf weeds such as cape weed and clovers, will help to control populations.

Several pesticides are registered for use on *Bryobia* mites; higher rates are usually required than for redlegged earth mites and blue oat mites. *Bryobia* mites have a natural tolerance to several chemicals.<sup>21</sup>

### 7.3.5 Brown wheat mite (*Petrobia latens*)

The mature brown wheat mite is about the size of a pinhead, globe-shaped and brown. It has been a sporadic pest of winter cereals. Populations reach troublesome levels only under very dry conditions.

## 7.4 Slugs

### 7.4.1 Description

Typically, the grey field slug (*Deroceras reticulatum*) is 35–50 mm long and light grey to fawn, with dark brown mottling (Figure 7). When disturbed, it will exude a sticky, milky secretion over its body. The black-keeled slug (*Milax gagates*) is 40–60 mm long and

<sup>19</sup> Agriculture Victoria (2000) The *Bryobia* mite and the pear-leaf blister mite. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/the-bryobia-mite-and-the-pear-leaf-blister-mite>

<sup>20</sup> GRDC (2012) Crop mites. Back Pocket Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2012/06/GRDC-Crop-Mites-Back-Pocket-Guide>

<sup>21</sup> GRDC (2012) Crop mites. Back Pocket Guide. GRDC, <http://www.grdc.com.au/Resources/Publications/2012/06/GRDC-Crop-Mites-Back-Pocket-Guide>

uniform black or brown with a ridge (keel) down its back (Figure 8). It can burrow to 20 cm underground.<sup>22</sup>



Figure 7: Grey field or reticulated slug (*Deroceras reticulatum*). (Photo: M Nash)



Figure 8: Black-keeled slug (*Milax gagates*). (Photo: M Nash)

### 7.4.2 Seasonal development and symptoms

Slugs are hermaphrodites; therefore, both individuals of a mating pair lay eggs. They will breed whenever moisture and temperature conditions are suitable—generally from mid-autumn to late spring. Eggs are laid in batches in moist soils and they will hatch within 3–6 weeks, depending on temperature. Juveniles look like smaller versions of the adult.

Slugs feed aboveground on stems and leaves, and belowground on seeds, shoots and roots. Damage is greatest when seedling growth is slow because of cool, wet or dry conditions. Grey field slugs are mainly surface-active, whereas black-keeled slugs burrow and can feed directly on germinating seeds. Slugs can be underestimated as pests because they are nocturnal and shelter during dry conditions, and therefore are not generally visible during daylight hours.<sup>23</sup>

### 7.4.3 Impact

Slugs damage newly sown crops and pasture, and damage is often difficult to detect or is incorrectly attributed to agronomic factors. If the population is large, damage to seedlings can be extensive. The black-keeled slug is more problematic in drier

<sup>22</sup> GRDC (2013) Slug identification and management. GRDC Slug control Fact Sheet, March 2013, <http://www.grdc.com.au/~media/412EEE56898A4AFB8B50409EC87FEBFE.pdf>

<sup>23</sup> GRDC (2013) Slug identification and management. GRDC Slug control Fact Sheet, March 2013, <http://www.grdc.com.au/~media/412EEE56898A4AFB8B50409EC87FEBFE.pdf>

environments such as South Australia, although it is widespread throughout south-eastern Australia.<sup>24, 25</sup>

#### 7.4.4 Management

Cultivation prior to sowing, delaying sowing after summer cover has been sprayed out, stubble and weed removal, and baiting are all effective methods for reducing slug populations. When slug pressure is high, baiting alone may not provide total crop protection.<sup>26</sup>

### 7.5 Aphids

#### 7.5.1 Oat or wheat aphid (*Rhopalosiphum padi*)

Oat or wheat aphid (Figure 9, Table 7) is one of the most common aphids infesting winter cereals. Typically, this species colonises the base and lower portions of the plant.<sup>27</sup>



Figure 9: Oat or wheat aphid. (Photo: QDAFF)

Table 7: Oat or wheat aphid management summary<sup>28</sup>

Scientific name	<i>Rhopalosiphum padi</i>
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. Wheat and oat aphids are very similar to <a href="#">corn aphids</a>
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 <i>Barley yellow dwarf virus</i> (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

<sup>24</sup> G Baker (2009) Pests of canola and their management. Ch. 9. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, [https://www.grdc.com.au/uploads/documents/GRDC\\_Canola\\_Guide\\_All\\_1308091.pdf](https://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf)

<sup>25</sup> GRDC (2013) Slug identification and management. GRDC Slug control Fact Sheet, March 2013, <http://www.grdc.com.au/~media/412EEE56898A4AFB8B50409EC87FEBFE.pdf>

<sup>26</sup> CropPro. Slugs. Pests in canola. CropPro, [http://www.croppro.com.au/cb\\_pages/pests\\_in\\_canola\\_-\\_in\\_crop.php?category\\_id=2381](http://www.croppro.com.au/cb_pages/pests_in_canola_-_in_crop.php?category_id=2381)

<sup>27</sup> 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>

<sup>28</sup> DAF Qld (2011) Oat aphid, wheat aphid. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/oat-aphid.-wheat-aphid>

Control	<p>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 <a href="#">Pest Genie</a> or <a href="#">APVMA</a></p> <p>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.</p>
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

### 7.5.2 Corn aphid (*Rhopalosiphum maidis*)

Corn aphid (Figure 10, Table 8) is also a common species found in winter cereals. It generally colonises the upper parts of the plant, particularly the rolled up terminal leaf.<sup>29</sup>



Figure 10: Corn aphid (*Rhopalosiphum maidis*). (PHOTO: QDAFF)

Table 8: Corn aphid management summary<sup>30</sup>

Scientific name	<i>Rhopalosiphum maidis</i>
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 in size
Similar species	Other species of <a href="#">aphids</a>
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

<sup>29</sup> 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>

<sup>30</sup> 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>

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 <a href="#">Pest Genie</a> or <a href="#">APVMA</a> for current control options.  Conservation of natural enemies: A range of parasitoids and predators will help reduce aphid populations. Predators of aphids include: ladybird larvae, damsel bugs, big-eyed bugs and the larvae of green lacewings and hoverflies. Wasp parasitoids mummify and kill aphids

### 7.5.3 Rose-grain aphid (*Metopolophium dirhodum*)

Rose-grain aphid (Figure 11, Table 9) generally colonises the undersides of the leaves, high in the canopy.<sup>31</sup>



Figure 11: Rose-grain aphid (*Metopolophium dirhodum*), adult and nymphs. (Photo: QDAFF)

Table 9: Rose-grain aphid management summary<sup>32</sup>

Scientific name	<i>Metopolophium dirhodum</i>
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 in size
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

<sup>31</sup> 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>

<sup>32</sup> 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-pest-list/aphid-overview/rose-grain-aphid>

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 <a href="#">Pest Genie</a> or <a href="#">APVMA</a>  Cultural control: There are no known effective cultural control methods for this aphid
Natural enemies	Predation by <a href="#">hoverflies</a> , <a href="#">lacewings</a> and <a href="#">ladybird beetles</a> , parasitism by wasps and heavy rainfall can reduce aphid populations

### 7.5.4 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.

## More information

[GRDC Fact Sheets: Cereal aphids. Northern Region](#)

## 7.6 Armyworm

Armyworms (Figure 12) 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.



Figure 12: Common armyworm (*Leucania convecta*). (Photo: QDAFF)

The most common species are common, inland and southern armyworms (*Leucania convecta*, *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 larva/m<sup>2</sup> can cause a grain loss of 70 kg/ha.day (Table 10). Larvae take ~8–10 days to develop through the final, most damaging instars, with crops susceptible to maximum damage for this period (Table 11).

Check for larvae on the plant and in the soil litter under the plant. The best time to do this is late in the day when armyworms are most active. Alternatively, look around the base of damaged plants where the larvae may be sheltering in the soil during the day. Using a sweep net (or 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 m<sup>2</sup> 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. Prior to 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-lobbing, 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/m<sup>2</sup>. 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.<sup>33</sup>

Table 10: Value of yield loss incurred by armyworm larvae (1 or 2/m<sup>2</sup>) per day, based on various grain values for wheat and an estimated loss, given 1 larva/m<sup>2</sup>, of 70 kg/ha

Considering these results, and the relatively low cost of controlling armyworm, populations of >1 large larva/m<sup>2</sup> in ripening crops warrant spraying

Value of grain (AUS/t)	Value of yield loss (\$) per ha per day	
	1 larva/m <sup>2</sup>	2 larvae/m <sup>2</sup>
\$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

<sup>33</sup> 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 11: Armyworm management summary <sup>34</sup>

Scientific name	<i>Leucania convecta</i> —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	<p>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.</p> <p>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 wheat head stays green later and armyworms feed along the heads and damage grain rather than excising the whole head</p>
Monitoring and action level	<p>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 cereal crops because they hide at the base of plants or under clods of soil during the day. Search at the base of plants and under clods of soil to estimate the number of larvae per m<sup>2</sup>. 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.</p> <p>Action level is 2 larvae/m<sup>2</sup> for barley, but other cereals are likely to tolerate slightly higher numbers</p>
Control	<p>Chemical control: A range of insecticides is registered for armyworm control in cereals. Insecticides should target larvae 10–20 mm long. Larvae &gt;20 mm long can be difficult to kill and may require higher rates of insecticide. If possible, spray late in the day as larvae are active at night. See <a href="#">Pest Genie</a> or <a href="#">APVMA</a> for current control options.</p> <p>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)</p>

<sup>34</sup> 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>



**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

## 7.7 Snails

Snail numbers can explode in seasons with wet springs, summers.

Snails appear to build up most rapidly in canola, field peas and beans. However, they can feed and multiply in all crops and pastures. Baiting before egg laying is therefore vital. Timing and choice of controls will depend on the season. Baiting should be ceased 8 weeks before harvest to avoid bait contamination in grain.

Understand the factors that determine effectiveness of control. Monitor snails regularly to establish numbers, types, activity and success of controls. To control snails, you will need to apply a combination of treatments throughout the year.

### 7.7.1 Description

Snails are a mollusc with a rasping tongue and one single muscular 'foot' for movement. Much of their body is encased in a shell, which they secrete as they grow.

### 7.7.2 Symptoms

Snails consume cotyledons and this may resemble crop failure. Shredded leaves, chewed leaf margins, and irregular holes all occur as a direct result of feeding damage by snails. They generally invade from crop edges.

### 7.7.3 Control

Free-living nematodes carrying bacteria that cause snail death may help to reduce populations under certain field conditions. Hard grazing of stubbles, cabling and/or rolling of stubbles, stubble burning, cultivation, and removal of summer weeds and volunteers are all effective management options. Molluscicidal baits are effective on mature snails, and IPM-compatible, but can be less effective on juveniles.<sup>35</sup>

## 7.8 Soil pests

Occurrence of soil-dwelling pests is difficult to predict, so advice on their control should be sought prior to sowing if any problems are foreseen. The most severe damage tends to occur in crops following pasture, or if stubble has been retained.<sup>36</sup>

### 7.8.1 Cutworm (*Agrotis* spp.)

Several species of cutworms (*Agrotis* spp.) (Figure 13) attack establishing cereal crops. As their name suggests, cutworm larvae sever the stems of young seedlings at or near ground level, causing the collapse of the plant (Table 12). Damage usually shows up as general patchiness or as distinct bare areas in a very short time. Controlling weeds in the fallow prior to planting will assist in reducing cutworm population and reduce crop damage. This should be done at least 3-4 weeks prior to sowing. Chemical control may be warranted if larval numbers exceed 2/0.5-m row in emerging crops. The best time to monitor is late afternoon-evenings when larvae feed. During the day, scratch away soil around damaged plants to find larvae sheltering in the soil. For more information

<sup>35</sup> CropPro. Snails. Pests in canola. CropPro, [http://www.croppro.com.au/cb\\_pages/pests\\_in\\_canola\\_-\\_in\\_crop.php?category\\_id=2382](http://www.croppro.com.au/cb_pages/pests_in_canola_-_in_crop.php?category_id=2382)

<sup>36</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf)

read, how to recognise and monitor for soil insects in: [Insect pest management in winter cereals](#).<sup>37</sup>



Figure 13: Cutworm (*Agrotis* sp.) larvae on soil surface. (Photo: J Wessels)

Table 12: Cutworm description and management summary<sup>38</sup>

Scientific name	<i>Agrotis</i> spp.
Description	Larvae are up to 50 mm long, hairless with dark heads and usually darkish bodies, often with longitudinal lines and/or dark spots. Larvae curl up and remain still if picked up. Moths are a dull brown-black
Similar species	May be confused with <a href="#">armyworms</a> and <a href="#">Helicoverpa</a> larvae
Crops attacked	All field crops. Crops are at most risk during seedling and early vegetative stages
Damage	Young caterpillars climb plants and skeletonise the leaves or eat small holes. Older larvae may also climb to browse or cut off leaves, but commonly cut through stems at ground level and feed on the top growth of felled plants. Caterpillars that are almost fully grown often remain underground and chew into plants at or below ground level. They usually feed in the late afternoon or at night. By day they, hide under debris or in the soil
Monitoring and action level	Inspect crop twice weekly in seedling and early vegetative stage. Larvae feed late afternoons and evenings. Chemical control is warranted when there is a rapidly increasing area or proportion of crop damage
Life cycle	Usually a single generation during early vegetative stages. Moths prefer to lay their eggs in soil in lightly vegetated (e.g. a weedy fallow) or bare areas. Early autumn egg-laying results in most damage to young cereals. Larvae hatch and feed on host plants right through to maturity. Mature larvae pupate in the soil. Under favourable conditions, the duration from egg-lay to adult emergence is 8–11 weeks, depending on the species

<sup>37</sup> 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>

<sup>38</sup> DAF Qld (2010) Cutworm. 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/soil-insects/cutworm>

Control	<p>Chemical control: Insecticide application is cost-effective. The whole crop may not need to be sprayed if distribution is patchy; spot spraying may suffice. See <a href="#">Pest Genie</a> or <a href="#">APVMA</a> for current control options.</p> <p>Cultural control: Control weeds 3–4 weeks prior to sowing.</p> <p>Natural enemies: Cutworms are attacked by a number of predators, parasites and diseases</p>
Pest status	Minor, widespread, irregular

## 7.8.2 Wireworms and false wireworms

### Importance

Wireworms and false wireworms are common, soil-inhabiting pests of newly sown winter and summer crops. Wireworms are the larvae of several species of Australian native beetles, which are commonly called ‘click beetles’, from the family Elateridae.

False wireworms are also the larval form of adult beetles, some of which are known as ‘pie-dish beetles’, which belong to another family (Tenebrionidae), and have distinctively different forms and behaviour. Both groups inhabit native grassland and improved pastures, where they cause little damage. However, cultivation and fallow decimates their food supply, and hence, any new seedlings that grow may be attacked and sometimes destroyed. They attack the seedlings at pre- and post-emergence of all oilseeds, grain legumes and cereals, particularly in light, draining soils with a high organic content.

The incidence of damage caused by wireworms and false wireworms appears to be increasing with increasing use of minimum tillage and short fallow periods.

## 7.8.3 False wireworms

In crops, false wireworms are mostly found in paddocks with high contents of stubble and crop litter. They may affect all winter-sown crops.

### Description

There are many and varied species of false wireworm, but they share some general characteristics. Larvae are cylindrical, hard-bodied, fast-moving, golden brown to black-brown or grey with pointed upturned tails or a pair of prominent spines on the last body segment. Several common groups (genera) of false wireworms are found in south-eastern Australia:

- Grey or small false wireworm (*Isopteron (Cestrinus) punctatissimus*). Larvae grow to ~9 mm in length. They are grey-green, have two distinct protrusions from the last abdominal (tail) segment (Figure 14), and tend to have a glossy or shiny exterior. Hence, they are most easily recognised in the soil on sunny days, when their bodies are reflective. The adults are slender, dark brown and grow to ~8 mm in length. Eggs are <1 mm in diameter. There are several species of this pest genus, but *I. punctatissimus* appears to be the species most associated with damage.
- Large or eastern false wireworm (*Pterohelaeus* spp.). The largest group of false wireworms, they are the most conspicuous in the soil and grow up to 50 mm in length. They are light cream to tan, with tan or brown rings around each body segment, giving the appearance of bands around each segment (Figure 14). The last abdominal segment has no obvious protrusions, although under a microscope, there are a number of distinct hairs. Adults are large, conspicuous and often almost ovoid beetles with black, shiny bodies (Figure 15).
- Southern false wireworm (*Gonocephalum* spp.) grows to ~20 mm in length and has body colour and marking similar to the large false wireworm. Adults are generally dark brown-grey, oval beetles, and sometimes have a coating of soil on the body. Adults have the edges of the body flanged, hence the common name pie-dish beetles.

- Bronzed field beetle (*Adelium brevicorne*) larvae are shiny dark brown, grow to 12 mm long, and are cylindrical with two distinct, upturned spines on the end of the body. Adults are shiny black with a slight bronze appearance, grow to 11 mm long and are present from spring to autumn. There is one generation per year.

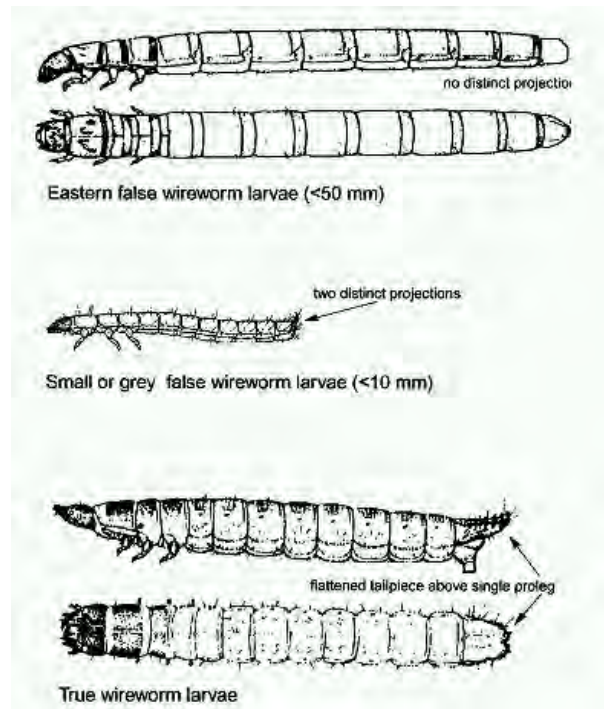


Figure 14: Two common false wireworm larvae and a 'generalised' true wireworm larva.

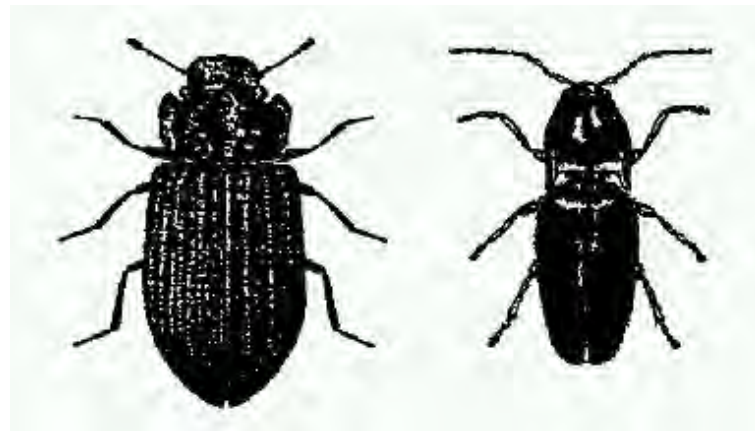


Figure 15: Adult (beetles) of the false wireworm (left) and true wireworm (right).<sup>39</sup>

### Seasonal development and symptoms

Larvae of most false wireworm species prefer to feed on decaying stubble and soil organic matter. When the soil is reasonably moist, the larvae are likely to aggregate in the top 10–20 mm where the plant litter is amassed. When the soil dries, the larvae move down through the soil profile, remaining in or close to the subsoil moisture, and occasionally venturing back to the soil surface to feed. Feeding is often at night when the soil surface becomes dampened by dew.

<sup>39</sup> G McDonald (1995) Wireworms and false wireworms. Agriculture Victoria, DEDJTR, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms>

Nothing is known of the conditions that trigger the switch in the feeding of false wireworms from organic matter and litter to plants. Significant damage is, however, likely to be associated with soils that remain dry for extensive periods. Larvae are likely to stop feeding on organic matter when it dries out, and when the crop plants provide the most accessible source of moisture.

### Impact

Affected crops may develop bare patches, which can be large enough to require resowing. Damage is usually greatest when crop growth is slow in cold, wet conditions.

The larger false wireworms can cause damage to most field crops. The larvae can hollow out germinating seed, sever the underground parts of young plants, or attack the aboveground hypocotyl or cotyledons. Damage is most severe in crops sown into dry seedbeds, and if germination is slowed by continued dry weather.

### Sampling and detection

The principles for detection and control of false and true wireworms are generally similar, although different species may respond slightly differently according to soil conditions.

Crops should be sampled immediately before sowing. Two methods are available, although neither is completely reliable. This is because larvae change their behaviour according to soil conditions, particularly soil moisture and temperature:

1. Soil sampling. Take a minimum of five random samples from the paddock. Each sample should consist of the top 20 mm of an area of soil 0.50 m by 0.50 m. Carefully inspect the soil for larvae. Calculate the average density per m<sup>2</sup> by multiplying the average number of larvae found in the samples by 4. Control should be considered if the average exceeds 10 small false wireworms, or 10 of the larger false wireworms.
2. Seed baits. Seed baits have been used successfully to sample true and false wireworms in Queensland and overseas but they have not been rigorously tested in Victoria. Preliminary work indicates that they can be used to determine the species of larvae present, and give an approximate indication of density. Pre-soak ~200–300 g of a large seed bait, such as that of any grain legume, for 24 h. Select 5–10 sites in the paddock, place a handful of the soaked seed into a shallow hole (50 mm), and then cover with about 10 mm of soil. Mark each hole with a stake, and re-excavate after ~7 days. Inspect the seed and surrounding soil for false wireworm larvae. This technique is most likely to be successful when there is some moisture within the top 100 mm of soil.

### Control

Crop residues and weedy summer fallows favour survival of larvae and overwintering adult beetles. Clean cultivation over summer will starve adults and larvae by exposing them to hot dry conditions, thus preventing population increases. Suitable crop rotations may also limit increases in populations.

If damage occurs after sowing, no treatment is available, other than resowing bare patches with an insecticide treatment.

#### 7.8.4 True wireworms

These slow-moving larvae tend to be less common, although always present, in broadacre cropping regions and are generally associated with wetter soils than is the case for false wireworms.

#### Description

Larvae grow to 15–40 mm, are soft-bodied, flattened and slow moving. This distinguishes them from false wireworms, which are hard bodied, cylindrical and fast moving. Their colour ranges from creamy yellow in the most common species to red

brown; their head is dark brown and wedge-shaped. The tailpiece is characteristically flattened and it has serrated edges (Figure 14). Adults are known as click beetles, because of their habit of springing into the air with a loud click when placed on their backs. They are dark brown, elongated and 9–13 mm long (Figure 15).

### *Seasonal development and symptoms*

There may be one generation or several per year, depending on species. Most damage occurs from April to August and adults emerge in spring. True wireworms prefer low-lying, poorly drained paddocks and are less common in dry soils. Larvae are quite mobile through the soil and they will attack successive seedlings as they emerge. Adults are typically found in summer and autumn in bark, under wood stacks or flying around lights.

Adult click beetles emerge in spring and summer, mate and lay eggs, and then may spend a winter sheltering under the bark of trees. The connection between trees and adult beetles may explain why damage is often, but not always, most pronounced on tree lines. True wireworms have a long life in the soil and are active all year, even in winter.

### *Impact*

The damage caused by true wireworms is similar to that of false wireworms, except that most damage is restricted to below the soil surface. Larvae eat the contents of germinating seed and underground stems of establishing plants, causing wilting and death.

### *Sampling, detection and control*

See above discussion on false wireworm for full details. Wireworms and false wireworms can be controlled only if they are detected in the seedbed before sowing. Insecticide can be applied to the soil with fertiliser, or seed can be treated.

## **7.8.5 Weevils**

Weevils are a diverse group of beetles commonly found in Australian grain crops (Table 13, Figure 16). Adult weevils appear very different from the larvae. Adults have a hardened body, six prominent legs and an elongated, downward-curved head forming a 'snout'. Larvae are legless, maggot-like in shape and may be confused with fly larvae. Weevil larvae possess a small, hardened head capsule.

Crop weevils feed on vegetative parts of crop plants including the roots, stems, shoots, buds and leaves. Both adults and larvae can be damaging to plants, depending on the species, crop type and time of year. Typical feeding damage observed is scallop-shaped holes along the edges of leaves.

Weevils can be difficult to control with chemicals because of their secretive habits. Several species are also patchy in their distribution within paddocks. For some species, seed treatments and foliar insecticides can provide a level of control.

Weevils are typically favoured by minimum tillage and stubble retention. Cultivation, burning and reducing the amount of stubble will reduce the suitable habitat for weevils and reduce their number. Identification of crop weevils is important when making control decisions. The distinctive appearance of weevils means that they are unlikely to be confused with other beetles. However, distinguishing between the many species of weevil is challenging. [Crop weevils: the Back Pocket Guide](#) is designed to assist growers in identifying the most commonly observed weevils found in the southern and western cropping regions.<sup>40</sup>

Weevil damage can occur at any time of the season, but feeding during autumn and early winter is typically the most critical. Inspect paddocks and nearby weeds prior to sowing and monitor crops for signs of seedling damage and bare patches within

<sup>40</sup> GRDC (2013) Crop weevils: the Back Pocket Guide. GRDC, <http://www.grdc.com.au/GRDC-BPG-CropWeevils>

paddocks. Look for signs of chewing damage on plants, often characterised by scallop-shaped holes along the leaf margins, ring-barking of seedlings, and loss of plant vigour. Searches may need to be undertaken during the night because is when weevils are most active.

Weevils, particularly larvae, can be difficult to control with chemicals because of their subterranean habits, meaning that they remain protected from insecticide exposure. Exceptions are the vegetable and grey-banded leaf weevils, whose larvae also feed on foliage. A few registered products are available for the active stages of several weevil species.<sup>41</sup>

Table 13: Description of common weevil species

Weevil species	Adult length (mm)	Distinctive features of adult weevils	Larval head capsule colour
Fuller's rose	8	Yellow or grey stripe on thorax and abdomen	Light
Grey-banded leaf	8	Pale band on rear of abdomen	Dark
<i>Mandalotus</i>	3-5	Dull brown, paddle-shaped bristles; short snout	Yellow-brown
<i>Sitona</i>	5	Three white strips on thorax; broad snout	Brown
Small lucerne	7	Less distinct lateral stripes than whitefringed	Light
Spinetail	7	Wing covers taper to spine (females); longer snout	Yellow
Spotted vegetable	5-7	Mottled-specked; longer snout	Brown
Whitefringed	10-15	Light lateral stripes	Light
Vegetable	10	Light-coloured 'V' at rear of abdomen	Brown



Figure 16: Small lucerne weevil (left) and Fuller's rose weevil (right). (Source: cesar)

### 7.8.6 Earwigs

Reports are increasing of European earwigs (*Forficula auricularia*) causing significant damage to emerging crops. Stubble retention in combination with wet springs and summers and an early autumn break appears to favour the build-up of these insects.

<sup>41</sup> Cesar (2015) Weevil pests. PestFacts south-eastern, issue 2, May 2015. cesar, <http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2015/pestfacts-issue-no-2-22nd-may-2015/weevil-pests/>

The damage caused by earwigs can be difficult to identify, and because control can also be difficult, growers should seek advice if they suspect or see earwigs.<sup>42</sup>

Correctly identifying earwig species is important because they have roles as pests or beneficial species. Not all earwigs found in crop paddocks are pests (Figure 17). Although European earwigs are renowned as pests, other earwigs can be benign or beneficial.

Other common earwig species include:

- Common brown earwig, *Labidura truncata*, which is a native and beneficial species. They are mostly red-brown and 10–45 mm in length. This species is most common in sandy habitats but occurs across southern Australia and mainly feeds on soft-bodied insects such as caterpillars, lucerne flea and mites. It can be distinguished by an orange triangle behind its head on the elytra (wing cases). Males have long slender forceps with a distinctive tooth near the middle of the inner edge.
- Black field earwig, *Nala lividipes*, which is a minor pest species of broadacre agriculture, only occasionally attacking crops. They are smaller, at about 15 mm long, shiny black, and can be a pest of seeds and seedlings. Adults have wings and can fly; nymphs resemble adults but are wingless. The black field earwig is omnivorous, meaning they can be a pest and a predator. They can attack wheat, sorghum, maize and sunflowers. They eat newly sown and germinating seeds and the roots of crops, resulting in poor establishment. Black field earwigs prey upon a range of insects, including wireworms and *Helicoverpa* spp.
- *Euborellia* spp. are small, dark-coloured earwigs ranging from 10 to 25 mm in size. There are many subspecies, and they can be difficult to distinguish. They are flightless and appear to form mating pairs that maintain a small territory. Male and females will often be found together and, at times, with a brood of young earwigs. Preliminary research indicates that they may not be plant feeders and are likely to be more predatory.



Figure 17: Top left: European earwig, *Forficula auricularia*—a pest species. Top right: common brown earwig, *Labidura truncata*—a native and predatory species. (Photos: DAFWA) Bottom: black field earwig, *Nala lividipes*—a predatory species and minor pest. (Photos: DAF Qld)

<sup>42</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf)



### Seasonal development

European earwigs complete one generation per year, although females can produce two broods in some years. They can survive in a range of environments and the length of their life cycle depends on temperature. At 25°C, development from egg to adult takes 9–10 weeks but at 15°C it takes up to 5 weeks longer. In winter, adult females lay batches of 20–80 white, oval eggs in burrows in the topsoil, which hatch in 2–3 weeks.

In some years, under favourable environmental conditions, earwigs may lay eggs in late spring to produce a second summer brood. There are several nymphal instars (stages between moults). Female earwigs remain in the burrow, protecting the eggs and nymphs.

### Impact

European earwigs mainly attack canola but will also attack cereals, lupins and some legume crops. Damage can be scattered because of their patchy distribution. Earwigs chew the stems and cotyledons of emerging seedlings, killing plants or slowing plant development. As the plant grows, foliar damage includes shredded leaf tips and jagged holes in leaves.

Earwigs can completely defoliate young seedlings, leaving only stems or bare ground in patches. They can also chew through seedpods. Earwigs feed together at night, and in many cases, damage will start along the edges of a paddock. Earwig damage to plant leaves resembles feeding damage caused by slugs. Damage has been reported mainly in the medium- and high-rainfall zones, including South Australia's Mid North and South East regions, Victoria's Western District and the South West Slopes of New South Wales. Nearly all cases of damage have occurred in paddocks where minimum or no-till practices were used with high stubble loads, and often on heavier soils.

### Management—windrowing and harvesting

Grain with high numbers of earwigs may require cleaning to meet delivery standards.

### Monitoring

It is important to distinguish earwig species in order to make the most appropriate management decision and accurately assess the risk of attack to emerging crop seedlings. Native earwig species can have an important role in IPM and in the control of other insects. Monitoring for earwigs is best conducted at night, using a torch, because they are nocturnal feeders.

Another approach is to set pitfall traps—a small plastic cup buried flush in the soil. A small amount of liquid in the bottom will help to contain the insects that fall into the trap. Traps should be left for at least 24 h and are useful for catching invertebrates.

## 7.8.7 Black Portuguese millipedes (*Ommatoiulus moreleti*)

In the last 5–10 years, the black Portuguese millipede (*Ommatoiulus moreleti*) (Figure 18) has been emerging as a sporadic but damaging pest of broadacre agriculture, particularly canola.

The increase has been linked to stubble retention, no-till farming practices and improvements in soil organic matter, which have provided a more favourable habitat for millipedes to survive and reproduce. Recent wet summers have contributed to a population build-up in some parts of southern Australia, and planting of more vulnerable crops has led to increased damage.

The black Portuguese millipede is native to Europe and has been accidentally introduced to other countries, including Australia, where it is now common across south-eastern Australia.



Figure 18: Black Portuguese millipede (*Ommatoiulus moreleti*). (Photo: Western Australian Museum)

### Description

The smooth, cylindrical body of the black Portuguese millipede distinguishes it from other native species, which often have rougher and more uneven bodies. They come from the same family as several native Australian millipedes and centipedes, called myriapods, meaning 'many-legged'. Measuring 30–45 mm, adult millipede bodies consist of up to 50 segments with each segment having two pairs of legs. When disturbed, they either curl up in a tight spiral or thrash to escape.

Native millipedes are widespread in low numbers, but black Portuguese millipedes are found in large numbers and are quite mobile for their size, especially after opening autumn rains. They can move several hundred metres in a year.

They are transported between properties and to new regions in plant material, infested soil and farm machinery.<sup>43</sup>

### Seasonal development and symptoms

Black Portuguese millipedes start mating in March and April and lay most of their eggs in April and May. Mature females lay ~200 yellowish white eggs the size of a pinhead, in a small hole they make in the soil.

An immobile, legless stage hatches from each egg and develops into the first active stage of the life cycle after ~7 days (Figure 19). This first stage has only three pairs of legs. Millipedes grow through a series of moults. At each moult, the millipede adds more legs and body segments until it is mature.

During the first year of life, millipedes are quite small and easily overlooked. After the first year, juveniles reach the seventh, eighth or ninth stage of development and they will be about 1.5 cm long. After this, they moult only in spring and summer.

During moulting, millipedes are vulnerable because the new cuticle (outside skin layer) is soft and easily damaged. Black Portuguese millipedes usually mature after 2 years when they are in the tenth or eleventh stage of growth.

Millipedes feed on leaf litter, damp and decaying wood, fungus and vegetable matter such as tender roots, mosses, pollen or green leaves on the ground. They can play a role in breaking down organic matter in the soil. As a result, they occur in greater numbers in undisturbed leaf litter and organic mulch and in areas where winter weeds, such as sour sobs and Salvation Jane, form a mostly continuous groundcover. Millipedes are not numerous in cultivated areas or bare ground.

<sup>43</sup> GRDC (2013) Millipedes and slaters in no-till systems. GRDC Black Portuguese millipedes and slaters Fact Sheet, October 2013, <http://www.grdc.com.au/GRDC-FS-Millipedes-Slaters>

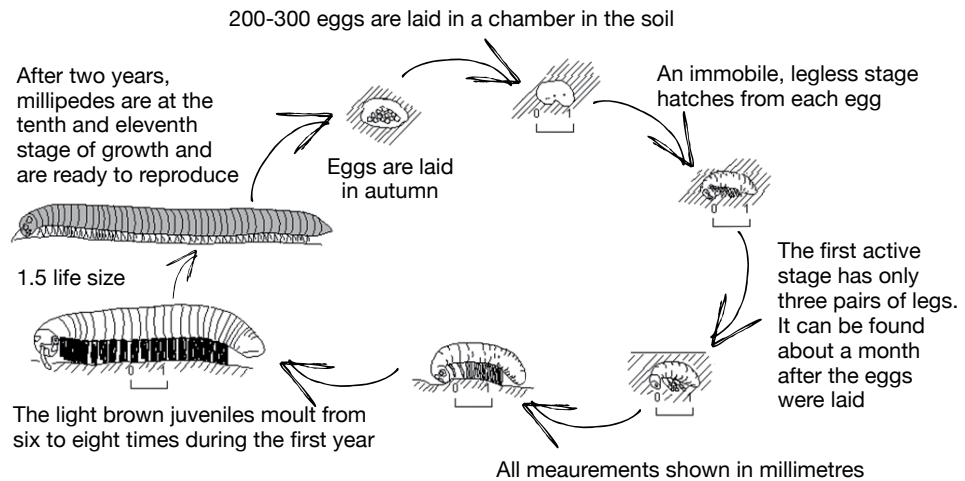


Figure 19: Life cycle of black Portuguese millipede.

### Impact

Because black Portuguese millipedes generally feed on organic matter, crop feeding damage is relatively rare. Black Portuguese millipedes occasionally attack living plants by chewing the leaves and stems. They may feed on crop plants when they are seeking moisture, but this has not been confirmed.

Damage to cereals can occur where the stems of young plants are chewed.

In the southern region, damage has been reported in the medium- and high-rainfall zones including near Wagga Wagga and Henty in New South Wales, the Mid North, Yorke Peninsula and Kangaroo Island in South Australia, and the Western District and Wimmera areas of Victoria. In many cases, damage has been worst in areas with high volumes of retained stubble or where plant matter from the previous year was present.

The presence of black Portuguese millipedes does not always mean damage. In many instances, no damage has occurred despite large populations of millipedes. Millipedes are mostly active and feed at night, which is the best time to check whether they are causing damage.<sup>44</sup>

### Management

Control options for millipedes are limited but some measures will curb populations. No insecticides are registered to control millipedes in broadacre agriculture.

#### Cultural

Reducing the amount of trash and stubble over summer and early autumn is likely to be the most effective way to reduce millipede numbers. Other factors to consider in management of crops and rotations include:

- Burning stubbles may reduce millipede populations.
- Early sowing of high-vigour varieties at a higher seeding rate will help to compensate for seedling losses from pest damage.

#### Biological

Millipedes have very few natural predators. Their bodies contain rows of glands that secrete a pungent yellowish fluid when they are agitated, and this fluid makes millipedes distasteful to predators such as birds.

A parasitic native nematode, *Rhabditis necromena*, attacks and kills millipedes by reproducing in the millipede's gut. However, the use of nematodes is unlikely to be economically viable for broadacre crop release.

<sup>44</sup> GRDC (2013) Millipedes and slaters in no-till systems. GRDC Black Portuguese millipedes and slaters Fact Sheet, October 2013, <http://www.grdc.com.au/GRDC-FS-Millipedes-Slaters>

Some spiders and beetles will eat millipedes but these predators will not significantly reduce large populations.

### 7.8.8 Slaters

Slaters perform an important recycling role in the environment. However, native and introduced slaters have become an increasing pest of broadacre crops and pastures. The move to minimum or no-tillage and stubble retention is likely to have created a more favourable environment in cropping paddocks for slaters. Stubble provides a cool, moist habitat, and crumbly clay soil surfaces and cracking clays aid their survival.

#### *Description and development*

Slaters are also known as woodlice, sowbugs and pill bugs. They are crustaceans, related to crabs, lobsters and prawns but are adapted to living on land. They have a hard skeleton on the outside of their bodies, seven pairs of jointed legs, and two pairs of antennae (Figure 20).

Most slaters are detritivores, meaning they feed on decaying vegetation and associated fungi, as well as on dead animal matter such as insects. They can eat living plants, such as seedlings and root vegetables, but only rarely.

Slaters need damp conditions and they will die if exposed to open and dry situations. They tend to be active at night when the risk of dehydration is low.

Female slaters keep their eggs in a pouch until the young hatch. Hatchlings then leave the parent and are completely independent. Slaters grow through a series of moults in which the outer rigid skeleton is shed, allowing growth to the next, larger stage and finally to adult stage. When moulting, slaters shed in two stages: the top half of their body first, followed by the remaining half 2 days later. During moulting, the slater is very vulnerable and must find shelter.<sup>45</sup>



Figure 20: Like black Portuguese millipedes, slaters generally feed on organic matter, and their populations and the incidence of crop attack have increased in recent years. (Photo: © NICK MONAGHAN, LIFEUNSEEN.COM)

<sup>45</sup> GRDC (2013) Millipedes and slaters in no-till systems. GRDC Black Portuguese millipedes and slaters Fact Sheet, October 2013, <http://www.grdc.com.au/GRDC-FS-Millipedes-Slaters>

## Species

Several slater species are found in Australia including:

- Common slater (*Porcellio scaber*). Originally introduced from Europe, the species is widespread in Australia. The common slater can grow up to 20 mm in length and is usually pale grey; however, brown, yellow or orange hues have been observed.
- Pill bug (*Armadillidium vulgare*). This is also a European species, introduced to Australia, and gets its name from its ability to roll into a ball when disturbed. It can grow up to 18 mm and is dark brown to black.
- Flood bug (*Australiodillo bifrons*). Populations of flood bugs have increased in parts of New South Wales. The flood bug is ~7–8 mm long and 4 mm wide with an oval-shaped and flattened body, light brown, with darker irregular spots and a dark-brown stripe down the middle of the back. It is a lowland, swampy-soil species. Areas worst affected in the past by flood bugs are prone to flooding.

## Symptoms

Little is known about the biology of slaters and their potential to become a widespread agricultural pest in Australia.

Slaters can cause significant feeding damage, leading to seedling mortality and stunted plant growth. In some situations, crops or parts of paddocks may need to be re-sown. Often, symptoms resemble feeding damage caused by lucerne flea.

Slater feeding on plants results in an uneven, rasping-type damage that can appear similar to slug and snail damage. They can chew the tops of emerging cotyledons or leaves of crop seedlings, leaving only the seedling stumps.

The flood bug in particular has potential to cause rapid damage to crops because of its ability to swarm. A consistent mass of slaters moves along the soil surface, climbing trees or moving into logs or posts (Figure 21). Swarms can contain >100,000 individuals, sometimes up to 1,000,000, and include all life stages, from juveniles to adults.

The size of swarms varies and is likely to be influenced by the time of day, weather conditions and surrounding vegetation. Thousands of seedlings can be eaten in a very short time when swarms are large enough.



Figure 21: Typical swarming behaviour of flood bug (*Australiodillo bifrons*) moving across a wheat paddock. (Photo: A Weeks, cesar)

### Impact

Slaters rarely attack broadacre crops; however, problems with slaters have increased considerably in the last 5 years. In south-eastern Australia, slaters have caused damage to wheat, oats, canola, lentils and pastures.

The presence of slaters, even in high numbers, in a paddock does not always mean that crop damage will occur, because slaters generally feed on decaying organic matter. Feeding on emerging crop seedlings is relatively rare. It is not known what makes slaters suddenly prefer to eat seedlings rather than organic matter.

In south-eastern Australia, damage has been reported in the medium- and high-rainfall zones including South Australia's Mid North and Yorke Peninsula, Victoria's Wimmera and Western Districts, and central New South Wales. In many cases (but not all), damage has been reported where there was an accumulation of stubble or other plant matter, or cracked soils.<sup>46</sup>

### Management

Management options are limited after crop emergence, so prevention is a key part of control. No insecticides are registered to control slaters. Slaters are relatively unaffected by many foliar applications of SPs and OPs to control other crop-establishment pests, even when applied at very high rates.

Managing stubble is likely to be the most effective strategy to reduce slater numbers. Some growers have had success managing slaters by burning crop residues.

## 7.9 Insect monitoring techniques for field crops

Monitoring for insects is an essential part of successful IPM programs. Correct identification of immature and adult stages of both pests and beneficials, and accurate assessment of their presence in the field at various crop stages, will ensure appropriate and timely management decisions. Good monitoring procedure involves not just knowledge of and the ability to identify the insects present, but also good sampling and recording techniques and common sense.

### 7.9.1 Factors that contribute to quality monitoring

Knowledge of likely pests or beneficials and their life cycles is essential when planning a monitoring program. As well as visual identification, you need to know where on the plant to look and the best time of day to get a representative sample.

Monitoring frequency and pest focus should be directed at crop stages likely to incur economic damage. Critical stages may include seedling emergence and flowering/grain formation.

Sampling technique is important to ensure that a representative portion of the crop has been monitored, because pest activity is often patchy. Defining sampling parameters (e.g. number of samples per paddock and number of leaves per sample) helps sampling consistency. Actual sampling technique, including sample size and number, will depend on crop type, age and paddock size, and is often a compromise between the ideal number and location of samples, and what is practical considering time constraints and distance covered.

Random sampling should be balanced with areas of obvious damage. Random sampling aims to give an overall picture of what is happening in the field, but any obvious hotspots should also be investigated. The relative proportion of hotspots in a field must be kept in perspective with less heavily infested areas.

### 7.9.2 Keeping good records

Accurately recording the results of sampling is critical for good decision making and

<sup>46</sup> GRDC (2013) Millipedes and slaters in no-till systems. GRDC Black Portuguese millipedes and slaters Fact Sheet, October 2013, <http://www.grdc.com.au/GRDC-FS-Millipedes-Slaters>

being able to review the success of control measures (Figure 22). Monitoring record sheets should show the following:

- numbers and types of insects found (including details of adults and immature stages)
- size of insects (particularly important for larvae)
- date and time
- crop stage and any other relevant information (e.g. row spacings, weather conditions, and general crop observations)

Site: *Cameron*  
 Date: *15/9/06*  
 Row spacing: *75cm*

Sample (1 m row beat)	VS	S	M	L
1	<i>3</i>	<i>5</i>	<i>1</i>	<i>0</i>
2	<i>1</i>	<i>1</i>	<i>1</i>	<i>0</i>
3	<i>3</i>	<i>3</i>	<i>0</i>	<i>1</i>
4	<i>3</i>	<i>2</i>	<i>1</i>	<i>0</i>
5	<i>2</i>	<i>6</i>	<i>0</i>	<i>0</i>
Average		<i>3.4</i>	<i>0.6</i>	<i>0.2</i>
Adjust for 30% mortality (S*0.7)	<i>3.4*0.7 = 2.4</i>			
Mean estimate of larval number (Adjusted S)+M+L	<i>2.4 + 0.6 + 0.2 = 3.2</i>			

Adjust for row spacing divide by row spacing (m)  $\frac{3.2}{0.75}$  4.2 Density Estimate per square metre

Figure 22: An example of a field check sheet for chickpeas, showing adjustments for field mortality and row spacings.

Consider putting the data collected into a visual form that enables you to see trends in pest numbers and plant condition over time. Being able to see whether an insect population is increasing, static or decreasing can be useful in deciding whether an insecticide treatment may be required, and if a treatment has been effective. If you have trouble identifying damage or insects present, keep samples or take graphs for later reference.

Records of spray operations should include:

- date and time of day
- conditions (wind speed, wind direction, temperature, presence of dew and humidity)
- product(s) used (including any additives)
- amount of product(s) and volume applied per hectare
- method of application including nozzle types and spray pressure
- any other relevant details

### 7.9.3 Sampling methods

#### Beat sheet

A beat sheet is the main tool used to sample row crops for pests and beneficial insects. Beat sheets are particularly effective for sampling caterpillars, bugs, aphids and mites. A standard beat sheet is made from yellow or white tarpaulin material with heavy dowel on each end. Beat sheets are generally 1.3–1.5 m wide and 1.5–2.0 m deep (the larger dimensions are preferred for taller crops). The extra width on each side catches insects thrown out sideways when sampling, and the sheet’s depth allows it to be draped over the adjacent plant row. This prevents insects being flung through or escaping through this row.

To use the beat sheet, place one edge at the base of plants in the row to be sampled.

Drape the other end of the beat sheet over the adjacent row. This may be difficult in crops with wide row spacing ( $\geq 1$  m); in this case, spread the sheet across the inter-row space and up against the base of the next row.

Using a 1-m stick, shake the plants in the sample row vigorously in the direction of the beat sheet 5–10 times. This will dislodge the insects from the sample row onto the beat sheet.

Reducing the number of beat sheet shakes per site greatly reduces sampling precision. The use of smaller beat sheets, such as small fertiliser bags, reduces sampling efficiency by as much as 50%.

Use the datasheets to record type, number and size of insects found on the beat sheet.

One beat does not equal one sample. The standard sample unit is five non-consecutive 1-m-long sections of row, taken within a 20-m radius, i.e. 5 beats = 1 sample unit. This should be repeated at six locations in the field (i.e. 30 beats per field).

Increasing the number of samples taken increases the accuracy of the assessment of pest activity, particularly for pests that are patchily distributed, such as pod-sucking bug nymphs.

When is the best time to use the beat sheet?

Crops should be checked weekly during the vegetative stage.

Caterpillar pests are not mobile within the canopy, and checking at any time of the day should report similar numbers.

Pod-sucking bugs, particularly green vegetable bugs, often bask on the top of the canopy during the early morning, and they are more easily seen at this time.

Some pod-sucking bugs, such as brown bean bugs, are more flighty in the middle of the day and therefore more difficult to detect when beat-sheet sampling. Other insects (e.g. mirid adults) are flighty no matter what time of day they are sampled, so it is important to count them first.

In very windy weather, bean bugs, mirids and other small insects are likely to be blown off the beat sheet.

Using the beat sheet to determine insect numbers is difficult when the field and plants are wet.

Although the recommended method for sampling most insects is the beat sheet, visual checking in buds and terminal structures may also be needed to supplement beat-sheet counts of larvae and other, minor pests. Visual sampling will also assist in finding eggs of pests and beneficial insects.

Most thresholds are expressed as pests per  $m^2$ . Hence, insect counts in crops with row spacing  $< 1$  m must be converted to pests/ $m^2$ . To do this, divide the 'average insect count per row metre' across all sites by the row spacing (in metres). For example, in a crop with a row spacing of 0.75 m (75 cm), divide the average pest counts by 0.75.

### Other sampling methods

Visual checking is not recommended as the sole form of insect checking; however, it has an important support role. Leaflets or flowers should be separated when looking for eggs or small larvae, and leaves checked for the presence of aphids and silverleaf whitefly. If required, dig below the soil surface to assess soil insect activity. Visual checking of plants in a crop is also important for estimating how the crop is progressing in terms of average growth stage and other agronomic factors.

Sweep-net sampling is less efficient than beat-sheet sampling and can underestimate the abundance of pest insects present in the crop. Sweep netting can be used for flighty insects and is the easiest method for sampling mirids in broadacre crops or crops with narrow row spacing. It is also useful if the field is wet. Sweep netting works best for smaller pests found in the tops of smaller crops (e.g. mirids in mungbeans), is less



efficient against larger pests such as pod-sucking bugs, and is not practical in tall crops with a dense canopy such as coastal or irrigated soybeans. At least 20 sweeps must be taken along a single 20-m row.

Suction sampling is a quick and relatively easy way to sample for mirids. Its main drawbacks are unacceptably low sampling efficiency, a propensity to suck up flowers and bees, noisy operation, and high purchase cost of the suction machine.

Monitoring with traps (pheromone, volatile, and light traps) can provide general evidence on pest activity and the timing of peak egg-lay events for some species. However, it is no substitute for in-field monitoring of actual pest and beneficial numbers.<sup>47</sup>

<sup>47</sup> DAF Qld (2012) Insect monitoring techniques for 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/help-pages/insect-monitoring>

## 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*.

Intolerant crops such as wheat can lose 20–60% in yield when nematode populations are high.<sup>1</sup> 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).<sup>2</sup>

*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.

Two races of stem nematode (*Ditylenchus dipsaci*) have been recorded in South Australia: the oat and the lucerne race. The oat race is found in parts of Yorke Peninsula and the Mid North of South Australia. The main hosts are susceptible varieties of oats and faba beans. Symptoms on oats include stunted plants and the bases of each tiller becoming swollen. Other crops such as field peas, chickpeas, canola and lentils are damaged extensively by stem nematode when they are seedlings (i.e. there is seedling intolerance). Symptoms include stunted and distorted leaves and stems. As crops mature, they become both resistant and tolerant.<sup>3</sup>

## 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. Wheat is susceptible to both *P. thornei* and *P. neglectus*.<sup>4</sup>

<sup>1</sup> KJ Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes: crop rotations to manage nematodes—key decision points for the latter half of the year, Bellata. GRDC Update Papers, 16 July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes>

<sup>2</sup> 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>

<sup>3</sup> GRDC (2015) Root-lesion nematodes. Plant Parasitic Nematodes Tips and Tactics, GRDC, February 2015, <http://www.grdc.com.au/TT-RootLesionNematodes> (Southern Region)

<sup>4</sup> 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>

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.

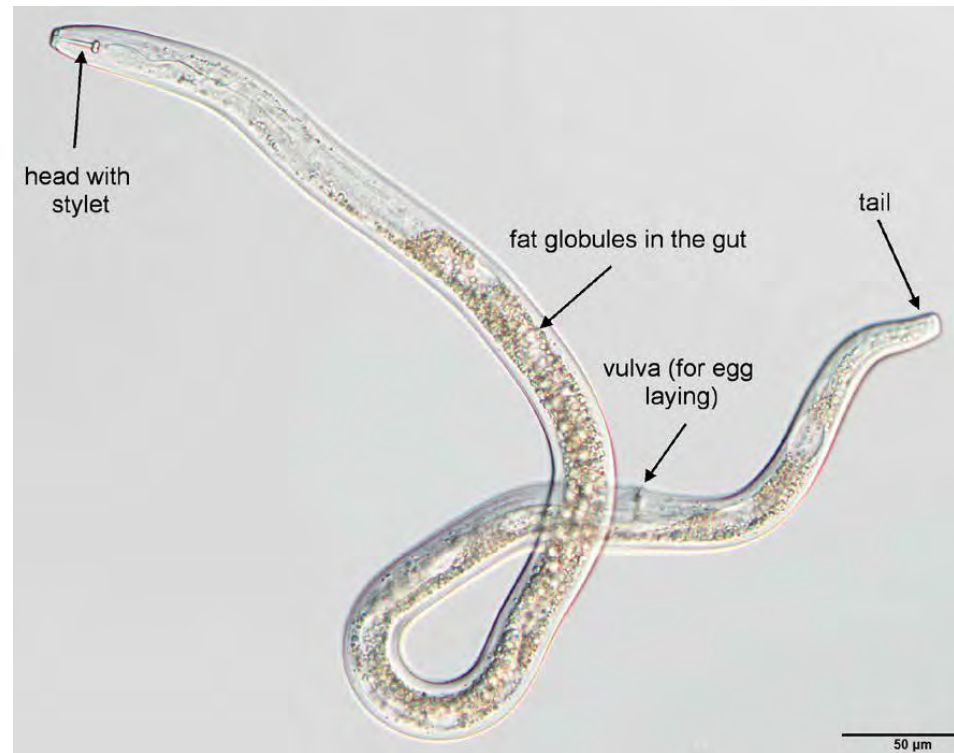


Figure 1: *Pratylenchus thornei* adult female viewed under the microscope. The nematode is approximately 0.65 mm long.

### 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 cycles within the plant each growing season, depending on temperature and moisture. The optimum temperature for nematode reproduction is 20°–25°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.

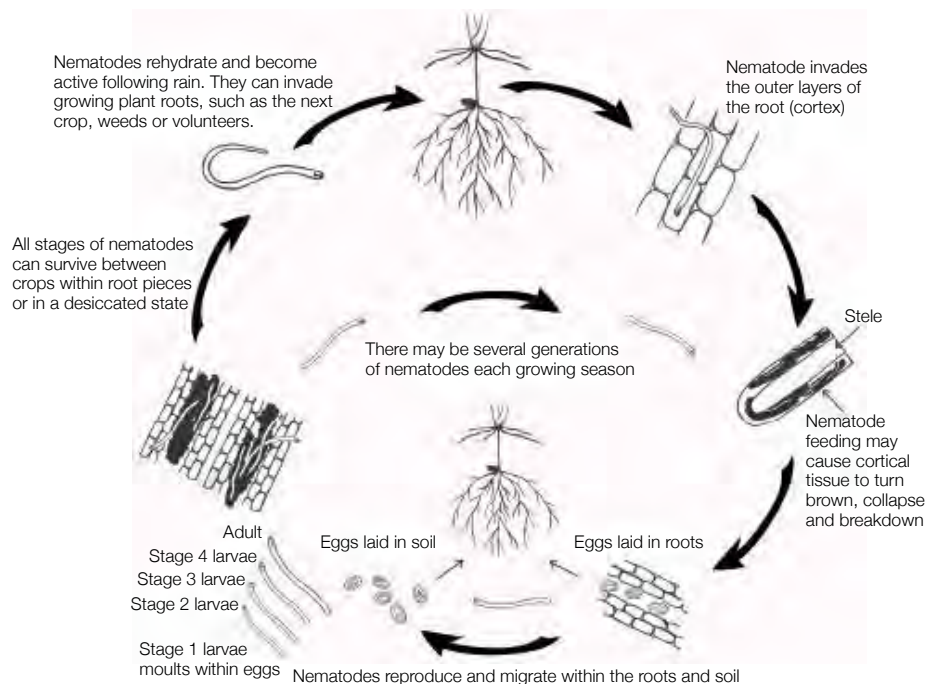


Figure 2: Disease cycle of root-lesion nematode, adapted from: GN Agrios (1997) Plant pathology, 5th edn (Academic Press: New York). (Illustration by Kylie Fowler)

### 8.1.2 Economic importance

In the Southern Region, high densities of RLN generally cause yield losses of 10–20% in wheat crops. The extent of damage, and subsequent grain yield loss, depend on seasonal conditions, the tolerance of the crop and the numbers of nematodes present at sowing. In field trials carried out by the Victorian and South Australian state departments from 2011 to 2013, *P. thornei* reduced grain yield in intolerant varieties by 2–12%, and *P. neglectus* by 2–8% (Table 1).

Table 1: Grain yield loss (%) caused by root-lesion nematodes in Victoria and South Australia. Values are average percentage yield loss in the five most intolerant wheat varieties

	<i>P. thornei</i>		<i>P. neglectus</i>	
	South Australia	Victoria	South Australia	Victoria
2011	7.7	12.2	No trial	4.3
2012	9.0	5.3	8.0	6.6
2013	No trial	2.4	3.8	2.6

## 8.2 Varietal resistance or tolerance

A tolerant crop yields well when large populations of RLN are present (in contrast to an intolerant crop). A resistant crop does not allow RLN to reproduce and increase in number (in contrast to a susceptible crop) (Tables 2 and 3).

Table 2: The four possible combinations of tolerance and resistance, with examples<sup>5</sup>

<b>Tolerant-resistant</b> e.g. sorghum cv. MR43 to <i>P. thornei</i> and wheat breeding lines released for development	<b>Tolerant-susceptible</b> e.g. wheat cv. EGA Gregory to <i>P. thornei</i>
<b>Intolerant-resistant</b> No commercial wheat lines in this category	<b>Intolerant-susceptible</b> e.g. wheat cv. Strzelecki to <i>P. thornei</i>

<sup>5</sup> K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes: crop rotations to manage nematodes – key decision points for the latter half of the year, Bellata. GRDC Grains Research Update, July 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes>

Table 3: Susceptibility and resistance of various crops to root-lesion nematodes<sup>6</sup>

RLN species	Susceptible	Intermediate	Resistant
<i>P. thornei</i>	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
<i>P. neglectus</i>	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

Wheat breeding has provided a number of varieties with moderate or higher levels of tolerance to *P. thornei*, e.g. Sunvale<sup>(b)</sup>, Baxter<sup>(b)</sup>, EGA Wylie<sup>(b)</sup> and EGA Gregory<sup>(b)</sup>. These varieties will reduce the level of yield loss due to *P. thornei*.

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 3):

1. Test soil for nematodes in a laboratory.
2. Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.
3. Choose tolerant wheat varieties to maximise yields ([National Variety Trials Online](#)). Tolerant varieties grow and yield well when RLN are present.
4. Rotate with resistant crops to prevent increases in RLN (Table 3, Figure 3). 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.<sup>7</sup>

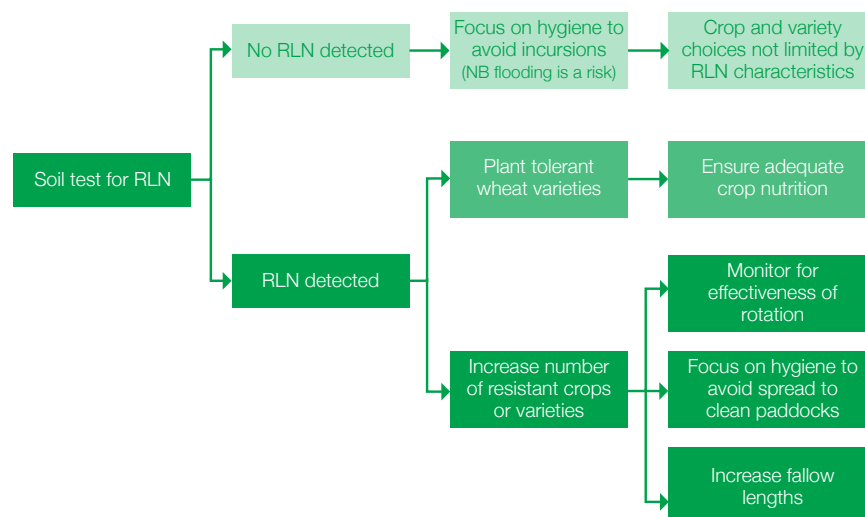


Figure 3: Root-lesion nematode management flow-chart.

<sup>6</sup> 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>

<sup>7</sup> 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>

Nematodes reduce yields in intolerant wheat 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% in the intolerant wheat variety Derrimut, 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, 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 wheat varieties

Resistance ratings for wheat varieties 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. These data appear to be a very useful addition to our current knowledge on varietal resistance, with relative variety performance fairly consistent across sites. Figure 4 shows the relative performance of a range of varieties as a percentage of EGA Gregory<sup>(1)</sup> in a wide range of trials during 2009–2012.

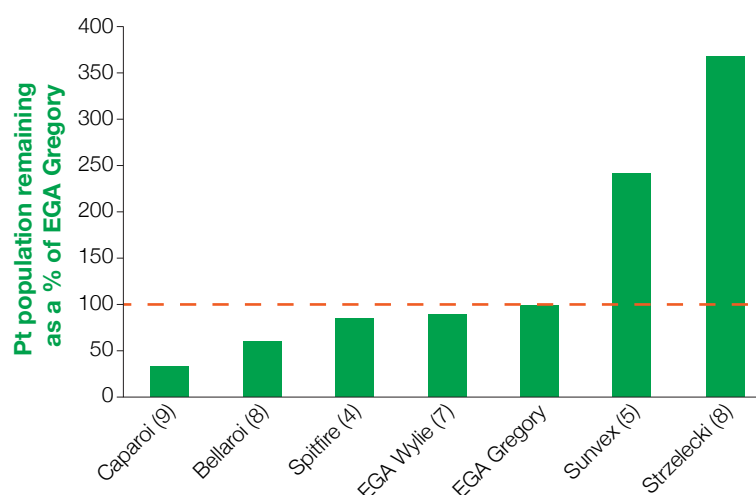


Figure 4: Comparison of *P. thornei* (Pt) population remaining as a percentage of EGA Gregory<sup>(1)</sup>, 2009–12. Values in parentheses are the number of trials in which the variety was compared with EGA Gregory<sup>(1)</sup>. The red broken line indicates the Pt level remaining after EGA Gregory<sup>(1)</sup>.

Bread wheats are generally susceptible to *P. thornei* but there are large differences between varieties in the level of susceptibility. Growers with *P. thornei* infestations must avoid ‘sucker’ varieties that result in very high levels of *P. thornei* multiplication. Although durum wheats generally restrict *P. thornei* multiplication compared with bread wheats, they are very susceptible to crown rot.<sup>8</sup>

Canola is now thought to have a ‘biofumigation’ potential to control nematodes, and a field experiment has compared canola with other winter crops or clean-fallow for

<sup>8</sup> R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Papers, 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>

reducing *P. thornei* population densities and improving growth of *P. thornei*-intolerant wheat (cv. Batavia) in the following year.

Immediately after harvest of the first-year crops, populations of *P. thornei* were lowest following various canola cultivars or clean fallow and highest following susceptible wheat cultivars (1957–5200 v. 31,033–41,294 *P. thornei*/kg dry soil). Unexpectedly, at planting of the second-year wheat crop, nematode populations were at more uniform, lower levels (<5000/kg dry soil), regardless of the previous season's treatment, and remained that way during the growing season, which was quite dry.

Growth and grain yield of the second-year wheat crop were poorest on plots previously planted with canola or left fallow because of poor colonisation with arbuscular mycorrhizal (AM) fungi, with the exception of canola cv. Karoo, which had high AM fungal colonisation and low wheat yields. There were significant regressions between growth and yield parameters of the second-year wheat and levels of AM fungi following the pre-crop treatments.

Canola appears to be a good crop for reducing *P. thornei* populations, but the dependence of subsequent crops on AM fungi should be considered.

## 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.<sup>9</sup>

Similar results can be obtained by testing soil, either by manual counting (under microscopes) or by DNA analysis (PreDicta B), with commercial sampling generally at depths of 0–15 or 0–30 cm.<sup>10</sup>

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, the majority of 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. Intolerant wheat varieties may appear stunted, with yellowing of lower leaves and poor tillering (Figure 5). These symptoms may not be present in other susceptible crops such as barley and chickpeas.<sup>11</sup>

<sup>9</sup> 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>

<sup>10</sup> 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>

<sup>11</sup> 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>



Figure 5: Aboveground symptoms of root-lesion nematode are often indistinct and difficult to identify. Affected plants (centre) generally show poor vigour and are often stunted, and cereals tiller poorly.

### 8.4.1 What is seen in the paddock?

Although symptoms of RLN damage in wheat can be dramatic, they 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 nutrition and soil water.

Visual aboveground damage from RLN is non-specific. Yellowing of lower leaves is often 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 wheat 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 more uniform, a random soil-coring approach may be more suitable. Another useful indicator of RLN presence is low yield performance of RLN-intolerant wheat varieties.<sup>12</sup>

### 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 using a shovel, not pulled from the ground. Pulling from the ground leaves most of the diseased roots behind. The roots must be carefully washed to remove the soil. Roots 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.

<sup>12</sup> 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>



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 wheat roots include darkening of the cortex and lack of root hairs.

## 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. This work has greatly improved the understanding of the impact of crown rot and variety tolerance, but also indicates that we may be suffering significant yield losses from another 'disease' that often goes unnoticed.

Although the trials were not designed to focus on nematodes, a convincing trend was apparent after 2008 indicating that *P. thornei* was having a frequent and large impact on wheat variety yield.

These trials were designed to evaluate the effect of crown rot on variety yield and quality. However, they strongly indicate that *P. thornei* is also having a significant impact on yield performance. The results do not compare the levels of yield loss from the two diseases but do indicate a greater range in variety of *P. thornei* tolerance than currently exists for crown rot tolerance.<sup>13</sup>

## 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

<sup>13</sup> 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>

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, PreDicta B, 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.

## SECTION 9

## Diseases

Diseases can severely affect yield and quality in wheat. 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 what crop is grown in what paddock the following year.
- Conduct in-fallow disease audits to determine the severity of the disease, e.g. yellow leaf spot and crown rot. This can also be used as a tool to determine what crop is grown in what paddock the following year.
- Send plant or stubble samples away for analysis to determine the pathogen or strain you are dealing with or the severity of the disease
- 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. <sup>1</sup>

Brennan and Murray (1988) published a detailed analysis of the cost of wheat diseases, based on the estimated yield losses as well as the cost of control measures. They estimated that in the 1980s, the annual cost of wheat diseases nationwide was AU\$400 million. Most alarming was that this translated to an average of \$34/ha. <sup>2</sup> With current yields, this figure is likely to be substantially higher.

Broadly, diseases can be caused by environmental factors such as temperature or water stress and nutrient deficiencies, as well as living agents (pathogens). Here we will consider only diseases with a biotic (living) cause. However, many diseases in grain crops, especially soil-borne diseases, have important interactions with environmental stresses. <sup>3</sup>

## 9.1 Causes of cereal diseases

Cereal diseases are caused by fungi, viruses, bacteria and nematodes.

### 9.1.1 Fungi

Fungi and other pathogens (disease-causing organisms) often reduce grain yields by damaging green leaves, preventing them from producing the sugars and proteins

<sup>1</sup> 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>

<sup>2</sup> J Brennan, G Murray (1988) Australian wheat diseases—assessing their economic importance. *Agricultural Science* (New Series), Vol. 1, pp. 26–35.

<sup>3</sup> UNE Agronomy of Grains Production course notes.

### More information

[GRDC: The current and potential costs from diseases of wheat in Australia](#)

[GRDC Fact Sheets: Green bridge control is integral to pest and disease management](#)

needed for growth. In other cases, they block or damage the plant's internal transport mechanisms, reducing the movement of water and sugars through the plant. Yields are also reduced when the pathogen diverts the plant's energy into reproducing more of the pathogen at the expense of plant growth or grain formation.

Fungi 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.

### 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.<sup>4</sup>

For more information, see [GrowNotes Wheat South Section 8. Nematodes](#).

## 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.

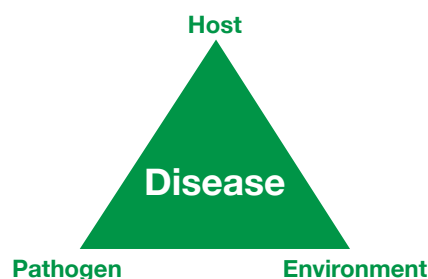


Figure 1: The disease triangle.

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:

<sup>4</sup> H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

- 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 below their optimum temperature.
- Pathogens have different optimum temperature ranges. For example, hatching in nematodes tends to occur over narrow soil temperature ranges, within a 10–25°C range 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 (see below). 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.<sup>5</sup>

Information on the main diseases affecting wheat, including their control, is presented in Table 1.

Table 1: Guide to wheat diseases

Disease	Organism	Symptoms	Occurrence	Inoculum source	Control
<b>Foliar</b>					
Leaf rust	<i>Puccinia triticina</i>	Small orange-brown powdery pustules on leaf.	Develops in spring. Favoured by mild (15°C–22°C) moist weather.	Airborne spores from living wheat plants.	Resistant varieties, control volunteer summer-autumn wheat. Seed dressings and foliar fungicides.
Stem rust	<i>Puccinia graminis</i> f. sp. <i>tritici</i>	Red-brown, powdery, oblong pustules with tattered torn edges on leaf and stem.	Can develop from mid spring into summer. Favoured by warm (15–30°C) humid conditions.	Airborne spores from living plants (wheat, barley, durum volunteer summer-autumn and triticale).	Resistant varieties, control wheat and barley. Foliar fungicides.
Stripe rust	<i>Puccinia striiformis</i> f. sp. <i>tritici</i>	Yellow powdery pustules often in stripes on leaves.	Can develop throughout the growing season. Favoured by cool (8–15°C), moist weather.	Airborne spores from living wheat and barley grass plants.	Resistant varieties, fungicides (seed, fertiliser and foliar), control volunteer summer- autumn wheat.
Septoria nodorum blotch (Glume blotch)	<i>Stagonospora nodorum</i>	Leaf lesions with minute black spots, leaf death. Can infect the head.	More common in early sown crops and in wet springs	Initially airborne spores released from stubble, and then spread by rain splashed spores within crop.	Resistant varieties, foliar fungicides, seed treatments, stubble removal.
Septoria tritici blotch	<i>Zymoseptoria tritici</i>	Leaf lesions with minute black spots, leaf death.	More common in early sown crops and in wet springs.	Initially airborne spores released from stubble, and then spread by rain splashed spores within crop.	Resistant varieties, foliar fungicides, seed treatments, stubble removal.
Yellow spot	<i>Pyrenophora tritici-repentis</i>	Leaf lesions often with yellow border, leaf death.	More severe in close rotations, when wheat is sown into wheat stubble.	Ascospores from stubble infect plants. Then secondary spread is by airborne spores in spring.	Stubble removal, crop rotation, foliar fungicides, resistant varieties.
BYDV	Barley yellow dwarf virus	Yellowing, dwarfing of infected plants, interveinal chlorosis, reduced seed set.	Most common in perennial grass pastures and in early sown crops.	A virus transmitted by aphids from infected grasses and cereals.	Resistant varieties, seed treatments and/or insecticide treatments to control aphids
<b>Grain</b>					
Bunt	<i>Tilletia laevis</i> T. <i>tritici</i>	Seed contains a black, foul smelling mass of spores. Affected grain is not accepted at silos.	Potentially region wide.	Spores on seed coat infect seedling before it emerges.	Seed applied fungicide.
Flag smut	<i>Urocystis agropyri</i>	Stunted plants with black, powdery streaks in leaves.	Most likely in crops sown early in warm soils.	Soil and seedborne spores.	Resistant varieties, seed-applied fungicide.
Loose smut	<i>Ustilago tritici</i>	Black powdery heads on diseased plants.	Region wide.	Infected seed is the predominant source.	Seed-applied fungicide.

<sup>5</sup> UNE Agronomy of Grains Production course notes.

Disease	Organism	Symptoms	Occurrence	Inoculum source	Control
<b>Root/crown</b>					
Common root rot	<i>Bipolaris sorokiniana</i>	Browning of the roots, sub-crown internode and the stem base. Brown spots on leaves. White heads and pinched grain.	Scattered through crop.	Soil borne on grass and cereal residues. Also as spores in the soil.	Crop rotation, one year free from hosts.
Crown rot	<i>Fusarium pseudograminearum</i> , <i>F. culmorum</i>	Browning of stem bases, crown and sometimes roots. White heads and pinched grain.	More severe following a wet winter and dry spring, especially on heavy soils which are poorly drained	Soil borne on grass and cereal residues.	Crop rotation. Avoid highly susceptible varieties, especially durum wheat.
Cereal cyst nematode (CCN)	<i>Heterodera avenae</i>	Yellow, stunted plants with knotted roots, often in patches.	Light soils and well structured clays where cereals are common.	Present in most soils in the southern region of Australia.	Resistant varieties, two year break from susceptible cereals and grasses, in particular wild oats.
Rhizoctonia bare patch	<i>Rhizoctonia solani</i> (AG 8)	Patches of stunted plants with yellow-red erect leaves. Spear tipped roots.	Associated with reduced tillage and poor weed control in autumn. Discouraged by soils with high organic matter.	Fungus carries over in organic matter in the soil. Wide host range.	Pre-cropping weed control, chemical fallow, cultivation, modified sowing equipment. Group B herbicides may increase severity on some soil types. Read the label.
Root lesion nematode	<i>Pratylenchus thornei</i> and <i>Pratylenchus neglectus</i>	Reduced tillering, ill thrift; a lack of root branching and lesions on roots.	Favoured by wheat in rotation with chickpea, medic and vetch.	Survive as dormant nematodes in the soil.	Crop rotation using resistant crops and resistant varieties.
Take-all	<i>Gaeumannomyces graminis</i> var. <i>tritici</i>	Blackening of roots, stem bases and crown. Plant stunting with white heads and pinched grain.	Favoured by a wet spring with a dry finish.	Soil borne on grass hosts and cereal residues.	Crop rotation, at least one year free of hosts (cereals and grasses, especially barley grass). Fungicide applied to seed or fertiliser.

This table has been developed from information in the publications Wallwork H (2000) (Ed) Cereal Root and Crown Diseases (Grains Research and Development Corporation, SARDI) and Wallwork H (2000) (Ed) Cereal Leaf and Stem Diseases (Grains Research and Development Corporation, SARDI).

### 9.3 Variety response

Wheat varieties carry varying tolerance and resistance to diseases (Table 2).

Table 2: Wheat variety disease ratings

	Rust			Pratylenchus								
	Stem	Stripe	Leaf	Yellow Leaf spot	Septoria tritici	CCN Res	<i>P. neglectus</i> resistance	<i>P. thornei</i> resistance	Crown rot	Common Root rot	Black tip (black point)	Flag smut
<b>Bread wheat</b>												
Axe	MS	RMR	Sp	S	SVS	S	MSS	MSS	S	MSS	S	S
Bolac	MRMS	RMR	S	S	MSS	S	MSS	MRMS	S	MSS	MSS	RMR
Chara	MRMS	MSS	Sp	MSS	MSS	R	SVS	MRMS	S	S	MS	MS
Condo	RMR	MSS	MRMSp	MSS	SVS	MR	S	MRMS	S	MSS	MRp	S
Corack	MR	MS	SVSp	MR	SVS	RMR	MSS	MRMS	S	MS	MSS	S
Correll	MRMS	MRMS	Sp	SVS	MSS	MR	MSS	MSS	S	MS	MS	R
Cosmick	MS	MSS	Sp	MRMS	S	MS	MS	MS	S	MSS	-	SVSp
Derrimut	MR	MSS	MSp	S	S	R	MSS	MSS	MSS	S	MSS	RMR
EGA Gregory	MR	MR	MR	S	MSS	S	MSS	MS	S	MSS	MSS	MSS
EGA Wedgetail	MRMS	MS	MS	MSS	MSS	S	S	S	S	-	MS	MRMS
Elmore CL Plus	MR	MRMS	RMR	S	MSS	S	SVS	MSS	S	MSS	MS	S
Emu Rock	MRMS	MRMS	S	MRMS	SVS	S	S	S	MS	MSS	MS	MS
Estoc	MR	MS	MRMS	MSS	S	MR	VS	MSS	MSS	MRMS	MS	MRMS
Forrest	RMR	RMR	MSSp	MRMS	MS	S	S	SVS	SVS	MS	MR	MR
Gladius	MR	MRMS	MS	MS	S	MS	MSS	S	S	MS	MS	RMR
Grenade CL Plus	MR	MRMS	Sp	S	S	MR	MSS	S	S	MRMS	MS	RMR
Justica CL Plus	MR	MRMS	Sp	S	S	MS	S	MSS	S	MS	S	R
Kellalac	MSS	MRMS	S	S	MS	MR	S	S	-	-	-	R
Kiora	RMR	RMR	MRMSp	MSS	S	MS	MSS	MRMS	S	MS	MSp	MRMS

	Rust				Pratylenchus							
	Stem	Stripe	Leaf	Yellow Leaf spot	Septoria tritici	CCN Res	<i>P. neglectus</i> resistance	<i>P. thornei</i> resistance	Crown rot	Common Root rot	Black tip (black point)	Flag smut
Kord CL Plus	MR	MRMS	MS	MSS	S	MR	S	MS	S	MRMS	MRMS	MR
Livingston	MRMS	MRMS	MSP	MS	S	MS	S	MS	S	S	MRMS	R
LRPB Cobra	RMR	MSS	MR	MRMS	MSS	MRMS	MSS	MSS	S	MSS	MSS	S
LRPB Dart	MR	MR	SVSp	MS	SVS	S	MSS	MS	MSS	MS	MRMSp	MSS
LRPB Gauntlet	RMR	MRMS	MS	MS	MS	MRMS	MSS	MR	MSS	MSS	MS	MS
LRPB Lancer	R	MR	RMR	MS	MSS	S	MSS	MS	MSS	S	MRMSp	MSP
LRPB Lincoln	MR	RMR	MSSp	MSS	S	S	MSS	SVS	SVS	MS	MR	RMR
LRPB Merlin	MR	MR	MS	S	S	MS	MSS	MSS	MSS	MSS	S	MRMS
LRPB Phantom	MS	MR	MSSp	SVS	SVS	MRMS	S	S	MSS	MSS	MRMS	MRMS
LRPB Scout	MR	MS	MRMS	SVS	SVS	R	S	MSS	S	S	S	MR
LRPB Spitfire	MR	MR	Sp	MSS	S	S	S	MS	MS	MS	S	MSS
LRPB Trojan	MRMS	MR	MRMSp	MSS	MSS	MS	MSS	MS	MS	MS	MRMS	SVS
LRPB Viking	MR	RMR	SVSp	MSS	S	Rp	S	MRMS			MRp	-
Mace	MR	SVS	MSSp	MRMS	S	MRMS	MS	MRMS	S	MS	MS	S
Magenta	RMR	MS	MS	MR	S	S	MSS	SVS	MSS	S	S	S
Merinda	RMR	MRMS	R	MSS	MSS	S	S	MSS	-	-	-	MSS
Sentinel 3R	RMR	RMR	R	MS	MRMS	S	S	MSS	MSS	S	MSS	MSS
Shield	RMR	MR	R	MSS	MSS	MR	MSS	MSS	S	MRMS	MS	S
Suntop	MR	MRMS	MRMSp	MSS	MSS	S	MSS	MR	MSS	MS	MRMS	R
Wallup	MRMS	MRMS	SVSp	MSS	S	MR	MS	MRMS	S	MS	MRMS	SVS
Yitpi	S	MRMS	Sp	SVS	MSS	MR	MSS	MSS	S	MS	MS	MR
Young	RMR	MS	MRMS	MS	MS	R	SVS	MSS	S	MSS	MR	MS
<b>Biscuit wheat</b>												
Barham	MRMS	S	MRMS	MSS	MSS	MS	MR	MSS	S	MSS	MRMS	MRMS
LRPB Gazelle	MR	MR	MR	MSS	MSS	S	S	S	-	MSS	MSS	S
LRPB Impala	MR	MR	SVSp	MSS	SVS	S	S	S	S	S	MRMS	SVS
Yenda	R	S	-	MRMS	-	S	MR	S	S	MSS	S	MR
<b>Durum wheat</b>												
Caparoi	MR	MR	MRMS	MRMS	R	-	MSS	MR	VS	MS	MSS	R
DBA Aurora	RMR	RMR	RMR	MRMS	MSP	Sp	MRMS	RMR	VS	MRMS	MS	R
EGA Bellaroi	MR	MR	MRMS	MRMS	MRMSp	-	MS	MR	VS	-	-	-
Hyperno	R	MR	RMR	MS	MRMS	MS	MS	RMR	SVS	MS	MS	R
Jandaroi	RMR	MR	MR	MS	MRMS	MS	MS	MRMS	VS	-	MSSp	R
Saintly	MR	MR	MRMS	MRMS	S	MS	MS	RMR	VS	MS	MS	R
Tjikuri	MR	MR	RMR	MS	MS	MS	MRMS	MR	VS	MS	MSS	R
WID802	RMR	MR	RMR	MS	MS	MS	MSS	MS	VS	MS	MSS	R
Yawa	RMR	MR	MR	MRMS	MR	MS	MS	RMR	VS	MRMS	MRMS	R
<b>Feed wheat</b>												
Beaufort	SVS	RMR	MSP	MRMS	S	S	MS	MS	S	MSS	MRMS	RMR
Manning	MR	RMR	RMR	MRMS	MR	S	MSS	S	VS	SVS	-	Rp
Naparoo	RMR	MR	S	MS	MS	-	SVS	SVS	S	S	-	VS
Preston	SVS	RMR	SVSp	MSS	S	S	MSS	MSS	S	MS	MRMS	S
SF Adagio	SVS	RMR	MSP	MRMS	MR	-	MS	MS	SVS	MSP	-	MS
SF Ovalo	S	R	MSP	MR	MRMS	-	MS	MS	SVS	MS	-	-
SF Scenario	MSS	MR	Sp	MS	MR	-	MSS	MS	SVS	MSP	-	-
SQP Revenue	RMR	R	Sp	MS	MS	S	MSS	MSS	S	SVS	MSS	S

# Varieties marked may be more susceptible if alternative strains are present. p = ratings are provisional - treat with caution.

R = Resistant RMR = Resistant to moderately resistant MR = Moderately resistant MRMS = Moderately resistant to moderately susceptible MS = Moderately susceptible MSS = Moderately susceptible to susceptible S = Susceptible SVS = Susceptible to very susceptible VS = Very susceptible.

## 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 with crown rot. 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 on effects on crown rot, Rhizoctonia root rot, inoculum, tan (yellow) spot, rusts, *Wheat streak mosaic virus* (WSMV), other cereal diseases, and burning stubble to control disease, see the NSW Department of Primary Industries (DPI) information sheet: [Cereal diseases after drought](#).<sup>6</sup>

### 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) (Figure 2), 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.<sup>7</sup>



Figure 2: Yellow spot (tan spot) infected stubble following flood. (Photos: Rachel Bowman)

<sup>6</sup> 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](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0004/123718/crop-diseases-after-drought.pdf)

<sup>7</sup> 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>



## 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.<sup>8</sup>

### 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<sup>9</sup>

## 9.6 Foliar diseases

Wheat can incur several foliar diseases, including:

- stem rust
- leaf rust
- stripe rust
- *Septoria tritici* blotch
- yellow (tan) spot
- BYDV
- eyespot
- powdery mildew

<sup>8</sup> 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>

<sup>9</sup> 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>

### 9.6.1 Diagnosing leaf diseases in wheat

Refer to Table 3 for the symptoms of leaf diseases in wheat.

Table 3: Diagnosing leaf diseases in wheat <sup>10</sup>

Disease	Spore colour	Symptoms	Plant part affected
Stripe rust	Yellow-orange	Small, closely packed circular pustules during the vegetative stage, becoming stripes along leaves of older plants	Upper surface of leaf, leaf sheaths, awns and inside glumes
Leaf rust	Orange-brown	Random, circular to oval pustules	Upper surface of leaf and leaf sheaths
Stem rust	Reddish brown	Random, oblong pustules with torn margins	Both sides of leaf, leaf sheaths, stems and outside of head
Yellow spot	Small tan (yellow brown) oval spots surrounded by a yellow margin	Spots up to 10 mm, varied shapes and may coalesce	Both sides of leaf, leaf sheaths, stems and outside of head

#### FAQ

### 9.6.2 Rusts—general information

In the Southern Region, there are three rust diseases of wheat: stem rust, leaf rust and stripe rust. They are caused by three closely related fungi, all belonging to the genus *Puccinia*.

The rusts are so-named because the powdery mass of spores that erupts through the plant's epidermis has the appearance of rusty metal. These spores can be spread over considerable distances by wind but may also be spread on clothing and equipment.

Wheat rusts have a number of features in common. They can infect only a limited number of specific host plants (mostly volunteer wheat, triticale and barley) and can survive only on green, growing plant tissue. Plants facilitating the survival of rust fungi through the summer are known as the 'green bridge'. These are alternative hosts as shown in Table 4, or volunteer cereals.

Table 4: Alternative hosts for cereal rusts <sup>11</sup>

Disease	Pathogen	Primary hosts	Alternative hosts	Symptoms
Leaf rust	<i>Puccinia triticina</i>	Bread and durum wheats, triticale	<i>Thalictrum</i> , <i>Anchusa</i> , <i>Isopyrum</i> , <i>Clematis</i>	Isolated uredinia on upper leaf surface and rarely on leaf sheaths
Leaf rust duri type	<i>Puccinia tritici-duri</i>	Durum and bread wheats in traditional agriculture	<i>Anchusa italica</i>	Isolated uredinia on lower leaf surface; fast teliospore development
Stem rust	<i>Puccinia graminis</i> f. sp. <i>tritici</i>	Bread and durum wheats, barley, triticale	<i>Berberis vulgaris</i>	Isolated uredinia on upper and lower leaf surfaces, stem and spikes
Stripe rust	<i>Puccinia striiformis</i> f. sp. <i>tritici</i>	Bread and durum wheats, triticale, a few barley cultivars	Unknown	Systemic uredinia on leaves and spikes and rarely on leaf sheaths

Rust diseases of wheat 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, wheat varieties that are resistant should be sown (i.e. MR, moderately resistant = 6, and above).

<sup>10</sup> DAF Qld (2012) Integrated disease management of wheat rusts and yellow spot. Key points to reduce the risk of rusts in wheat. Department of Agriculture, Fisheries and Forestry Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

<sup>11</sup> RP Singh, J Huerta-Espino, AP Roelfs. The wheat rusts. FAO, <http://www.fao.org/docrep/006/y4011e/y4011e0g.htm>

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 [Plant Breeding Institute \(PBI\) site](#) and [publications](#) 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.<sup>12</sup>

To keep up to date with rust incursions throughout the winter crop season, subscribe to the PBI [Cereal Rust Report](#).

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 wheat*

- Destroy volunteer wheat 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.

<sup>12</sup> 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>

## **i** More information

[GRDC Fact Sheets: Adult plant resistance](#)

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.<sup>13</sup>

### *Recommended fungicides for rusts*

To keep up to date with the latest recommended fungicides for rusts, visit: [Australian Pesticides and Veterinary Medicines Authority](#).

The three top leaves in wheat make the greatest contribution to yield, so the aim of any stripe-rust management strategy in susceptible varieties is to keep these leaves largely clean of infection. However, when applying a fungicide at GS25, these important leaves have not emerged, so they are unprotected by fungicide once they do come out.

Recent research shows that delaying the first fungicide application to GS32, when the flag-2 leaf has emerged, protects this leaf from infection and reduces the time, and subsequent disease build-up, until the second spray is applied at full flag-leaf emergence (GS39). Delaying the first spray from GS25 until GS32 returned an additional AU\$55/ha under high disease pressure and \$42/ha under moderate disease pressure in the MS (moderately susceptible) variety Ellison<sup>(1)</sup>.

A common strategy used in medium–high-rainfall areas is to use flutriafol on the fertiliser, followed by a foliar fungicide at GS39 for varieties with some susceptibility (very susceptible varieties may also require a fungicide at GS32).

### 9.6.3 Stem rust



Figure 3: Stem rust in wheat. (Photo: DAF Qld)

Stem rust is caused by the fungus *Puccinia graminis* f. sp. *Tritici* (Figure 3). It can attack wheat, barley, rye and triticale.

Stem rust produces reddish brown spore masses in oval, elongated or spindle-shaped pustules on the stems and leaves. Unlike leaf rust, pustules erupt through both sides of the leaves. Ruptured pustules release masses of stem rust spores, which are disseminated by wind and other carriers.

<sup>13</sup> GRDC (2012) Adult plant resistance. Northern, Western and Southern Regions. GRDC Fact Sheet, 2 Nov. 2012, <http://www.grdc.com.au/GRDC-FS-AdultPlantResistance>

Stem rust develops at higher temperatures than the other wheat rusts, within a range of 18–30°C. Spores require free moisture (dew, rain or irrigation) and take up to 6 hours to infect the plant, and pustules can be seen after 10–20 days of infection.

In Victoria, conditions that favour stem rust epidemics are rare and occur, on average, once every 16 years. However, when conditions are conducive, the disease can cause complete crop loss in susceptible varieties. With increased cultivation of stem-rust resistant varieties and greater availability of effective foliar fungicides, severe losses to stem rust are now less likely. In recent years, there have been few localised occurrences of stem rust in Victoria. Following the exceptionally wet January of 2011, a large amount of inoculum was carried over, resulting in extensive stem rust during 2011. Despite this, the widespread use of chemicals helped to minimise losses from the disease.<sup>14</sup>

Inoculum must be present for the disease to develop. Practicing crop hygiene by removing volunteer wheat, which forms a green bridge for the fungus through the summer, can eliminate or delay the onset of stem rust.

### More information

[NSW DPI: Strip rust: understanding the disease in wheat](#)

[ACRCP: The Rust Bust](#)

## 9.6.4 Leaf rust

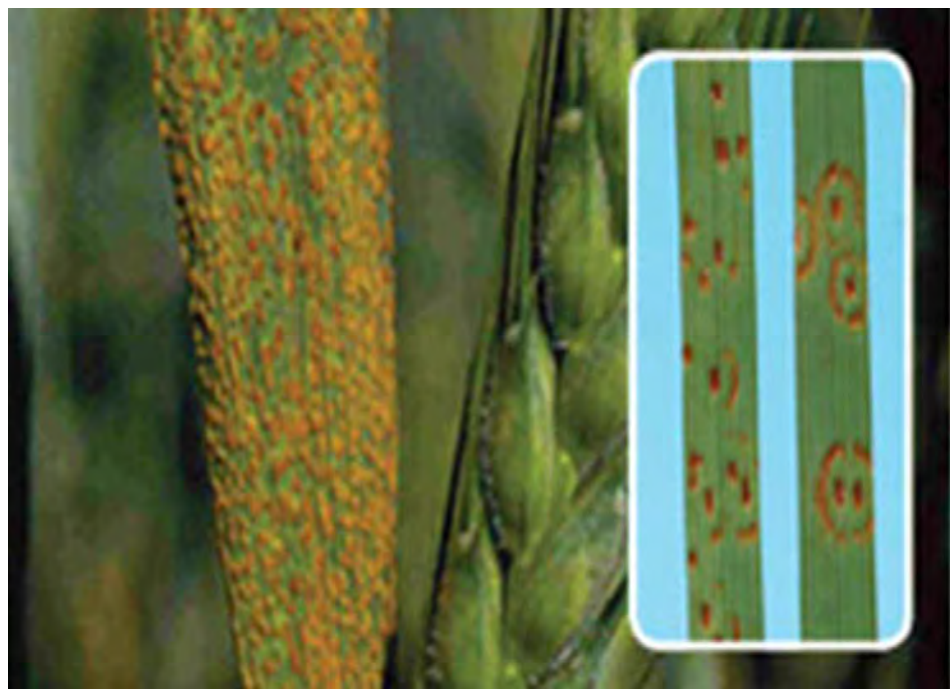


Figure 4: Leaf rust in wheat. (Photo: DAF Qld)

Leaf rust (Figure 4) is caused by the fungus *Puccinia triticina* (previously called *Puccinia recondite* f. sp. *tritici*). The disease can also infect rye and triticale.

Leaf rust produces reddish orange spores that occur in small, 1.5-mm, circular to oval pustules. These are found on the top surface of the leaves, distinguishing leaf rust from stem rust, which is found on both surfaces of the leaf.

The spores require temperatures of 15–20°C and free moisture (dew, rain or irrigation) on the leaves to infect wheat successfully. The first signs of the disease (sporulation) occur 10–14 days after infection. Removal of volunteer wheat plants, which form a green bridge for the fungus through the summer, can eliminate or delay the onset of leaf rust.

A new strain of wheat leaf rust was detected at multiple locations in Victoria during 2014. Many cultivars are now one rating more susceptible than previously. Several cultivars (including Axe<sup>®</sup>, Beaufort<sup>®</sup>, Corack<sup>®</sup>, Derrimut<sup>®</sup>, Mace<sup>®</sup>, SQP Revenue<sup>®</sup>, and

<sup>14</sup> G Hollaway (2014) Stem rust of wheat. AG1251. Revised May 2014. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/stem-rust-of-wheat>

Wallup<sup>(1)</sup> are now two or more rating levels more susceptible. The new ratings were marked as provisional in 2015, with only have one season of data. It is likely that this new leaf rust will be dominant in Victoria during the coming years so growers need to be more vigilant with leaf rust control. <sup>15</sup>

### 9.6.5 Stripe rust



Figure 5: Stripe rust in wheat. (Photo: DAF Qld)

Stripe rust is caused by the fungus *Puccinia striiformis*. It is easily distinguished from other wheat rusts by the orange-yellow spores, which produce small, closely packed pustules developing into stripes along the length of the leaf veins (Figure 5). The spores occur on the upper surface of the leaves, the leaf sheaths, awns and inside of the glumes.

Stripe rust requires cool and wet conditions to infect the crop. Free moisture on the leaves and an optimal temperature of 10–15°C are required for infection. Pustules erupt within 10–14 days after infection.

If the weather is conducive to stripe rust, the disease can cause up to 25% yield loss on varieties scoring MR–MS (= 5) or lower provided there is inoculum from a neglected green bridge or from an infected crop.

Several fungicides are recommended for the control of stripe rust. Fungicides can be incorporated with the fertiliser or applied as seed dressings to delay the onset of disease. Later, if 'money' leaves (the flag leaf and the two leaves below it) require protection, recommended foliar fungicides can be applied. <sup>16</sup>

### 9.6.6 Septoria tritici blotch

*Septoria tritici* blotch (STB) is caused by a fungus, *Zymoseptoria tritici* (synonyms *Mycosphaerella graminicola*, *Septoria tritici*), which survives in wheat stubble. Initial infection arises from ascospores produced within fruiting bodies (pseudothecia) on the

#### More information

[GRDC Update Papers: Stripe rust – prevention is generally best](#)

[GRDC Update Papers: Fungicide management of strip rust in wheat: up-front vs in-crop options](#)

<sup>15</sup> G Hollaway, M McLean, J Fanning (2015) Cereal disease guide. AG1160. Revised February 2015. DEDJTR Victoria, <http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-disease-guide>

<sup>16</sup> DAF Qld (2012) Integrated disease management of wheat rusts and yellow spot. Key points to reduce the risk of rusts in wheat. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

## More information

GRDC Fact Sheets:  
[Managing \*Septoria tritici\* blotch in wheat](#)

stubble. These windborne spores can travel over long distances. Secondary, short-distance dispersal is caused by different spores, called conidia, which are produced on the infected leaves. These are predominantly dispersed by splash from raindrops. <sup>17</sup>

### Host range

The fungus can infect all bread wheat, durum and triticale varieties to some degree. Although most Australian durum wheats and triticales have good resistance, growers need to consult a current cereal variety disease guide (e.g. [PIRSA Cereal disease guide](#), [Agriculture Victoria Cereal disease guide](#)) for individual variety resistance ratings. The fungal population differs in virulence across Australia so ratings in different regions may vary.

Wheat STB can occasionally infect oats and barley plants but those crops rarely develop significant levels of disease. However, both oats and barley can be infected by specialised forms of *Septoria* that have leaf symptoms similar to wheat STB (e.g. *Septoria tritici* f. sp. *avenae* on oats).

### Risk factors

Farm practices such as early sowing, minimum tillage, stubble retention, wheat-wheat crop sequences and growing susceptible wheat varieties are the main risk factors that increase the chance of infection. Weather conditions are also an important risk factor. Infection by the fungus is much greater with frequent rain events and where moist conditions extend over long periods. <sup>18</sup>

### Symptoms

*Septoria tritici* blotch in wheat causes brown lesions (Figure 6). In the more susceptible varieties, the lesions can appear silver-grey. The lesions tend to run parallel to the leaf veins. Black fruiting bodies (pycnidia) are usually visible on the dead leaf tissue. In the southern grain-growing region, favourable conditions for infection rarely persist into spring, so infection of the upper canopy is less common. In high-rainfall zones when conditions are favourable, lesions can spread across the leaf, forming large blotches. In wet springs, if infection appears after flowering, the glumes may become diseased.

As the plant matures, the fungus grows and feeds on decaying organic matter, which leads to infection of the stubble and survival of the fungus into the following season. The survival of STB on the stubble means that a break crop is necessary to reduce disease carryover. <sup>19</sup>

<sup>17</sup> GRDC (2014) Managing *Septoria tritici* blotch disease in wheat. Southern Region. *Septoria tritici* Blotch Fact Sheet, <http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat>

<sup>18</sup> GRDC (2014) Managing *Septoria tritici* blotch disease in wheat. Southern Region. *Septoria tritici* Blotch Fact Sheet, <http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat>

<sup>19</sup> GRDC (2014) Managing *Septoria tritici* blotch disease in wheat. Southern Region. *Septoria tritici* Blotch Fact Sheet, <http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat>



Figure 6: A wheat plant with typical symptoms of *Septoria tritici* blotch. (Photo: Andrew Milgate)

### Disease cycle

The fungus *Zymoseptoria tritici* can survive in crop stubble and plant debris for more than one season. The length of survival depends on the rate of stubble breakdown. In autumn–winter, the fungus develops sexual fruiting bodies that appear as black, pinhead-sized structures that sit at, or just below, the surface of the stubble and leaf blades.

Primary infection is mostly initiated by sexual spores (ascospores) produced in the fruiting bodies. Ascospores become airborne and can infect young plants in early-sown crops. The airborne nature of the spores means they can infect surrounding crops and regions. Secondary spread within the crop occurs from rain-splash by asexual fungal spores (conidia) produced on infected leaves. Temperatures of 15–20°C with rain followed by at least 6 hours of leaf wetness or dew are optimal for infection. <sup>20</sup>

### Strain types

Different strains (pathotypes) of *Z. tritici* have been found throughout the cropping zone, resulting in different variety ratings. Resistant varieties may become more susceptible over time as the pathogen adapts to the resistance genes carried by the plants. Growers should check the resistance rating of varieties in their region by using a current disease guide, but also be aware that if a variety is susceptible in neighbouring regions, there is a risk of that strain migrating into a new area. <sup>21</sup>

<sup>20</sup> GRDC (2014) Managing *Septoria tritici* blotch disease in wheat. Southern Region. *Septoria tritici* Blotch Fact Sheet, <http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat>

<sup>21</sup> GRDC (2014) Managing *Septoria tritici* blotch disease in wheat. Southern Region. *Septoria tritici* Blotch Fact Sheet, <http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat>



## Management

An integrated approach that incorporates crop rotation, variety selection, stubble management and fungicides (if required) can provide effective suppression of STB.

### Crop rotation

*Septoria tritici* blotch survives on cereal stubble between crops, specifically where wheat on wheat is sown. After a very dry season, the fungus may survive over 18 months and infect second-year crops. In most instances, a 1-year rotation out of wheat is highly effective in reducing early disease occurrence.

### Variety selection

Variety choice has a major influence on STB development in crops. Resistance ranges from MR to very susceptible (VS); however, growers should check their local current variety disease guide and ensure that they make appropriate selections. Where wheat is to be sown into wheat stubble, it is best to avoid varieties that are rated susceptible (S), S-VS or VS.

### Stubble management

Any tillage practice that reduces stubble density on the surface will reduce the level of inoculum. Surface stubbles may be reduced by burial, burning or grazing. Stubble reduction must be balanced against the increased risk of soil erosion by wind or water, especially in light soils. Stubble management will not reduce disease caused by spores blown in from other fields early in the season.

### Fungicide management

Most STB in south-eastern Australia occurs only at early seedling growth stages. If wet conditions persist, such as in high-rainfall zones, and susceptible varieties have been sown, then fungicides may provide some useful control. In high-risk areas, the timing of fungicides will be important to achieve adequate disease control. In early-sown susceptible varieties, an early fungicide application at GS31–32 may be required to suppress the disease and protect emerging leaves. Once the flag leaf has fully emerged at GS39, another fungicide application may be required to protect the upper canopy. Azole fungicides are used in combination with variety resistance to control STB in south-eastern Australia. Growers need to use fungicides in a way that prolongs their effectiveness.

Changes in STB resistance to fungicides have been detected in the southern grain-growing region, especially where wheat is sown into wheat stubble. Variety selection and crop rotations are essential for effective disease control.<sup>22</sup>

## 9.6.7 Tan (yellow) spot

Tan spot or yellow spot causes tan–brown flecks turning into yellow brown, oval spots or lesions surrounded by yellow margins (Figure 7); lesions may expand to 10–12 mm in diameter. Large lesions coalesce with dark brown centres. Spot develops on both sides of leaves. Temperatures of 20–30°C and free moisture favour disease development. In susceptible cultivars, yellow spot can cause up to 30% yield losses. A break from wheat-on-wheat (crop rotation with non-host crops) can reduce the risk of yellow spot. Sow resistant varieties; see the wheat variety guides.<sup>23</sup>

Yellow spot is caused by the fungus *Pyrenophora tritici-repentis*. It survives in wheat and occasionally triticale stubble. In rare cases, the fungus may survive in barley stubble. Wet spores (ascospores) develop in fungal fruiting bodies on wheat stubble, spread during wet conditions, and can infect growing wheat plants.

<sup>22</sup> GRDC (2014) Managing *Septoria tritici* blotch disease in wheat. Southern Region. *Septoria tritici* Blotch Fact Sheet, <http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat>

<sup>23</sup> DAF Qld (2012) Integrated disease management of wheat rusts and yellow spot. Key points to reduce the risk of rusts in wheat. Department of Agriculture and Fisheries Queensland, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/wheat-rusts>

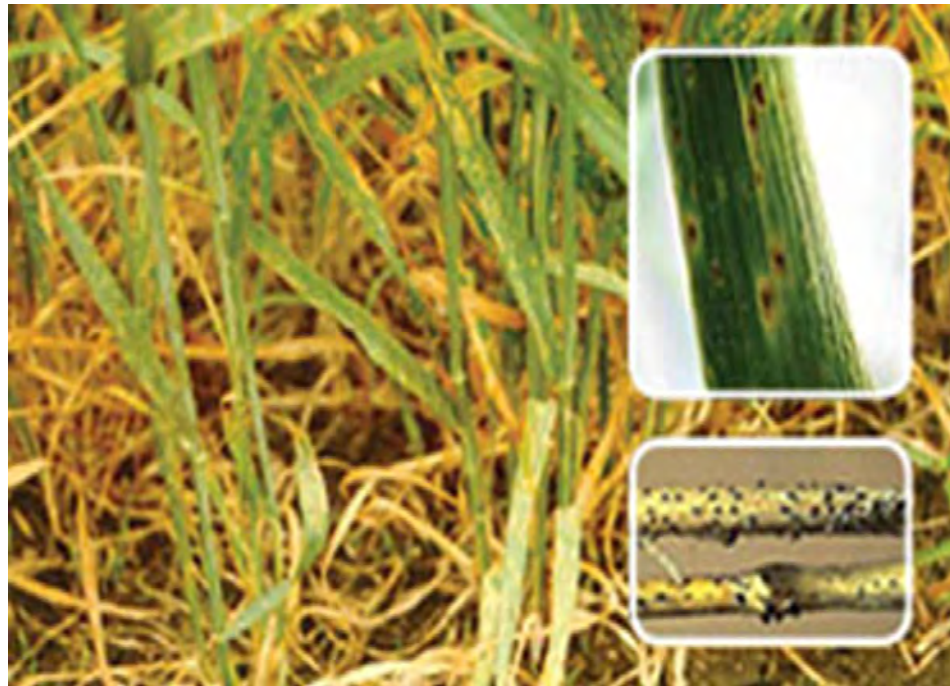


Figure 7: Tan spot in wheat. (Photo: DAF Qld)

### *Disease development and yield loss*

As the crop develops, masses of a second type of spore (conidia) are produced on old lesions and dead tissues. Conidia result in rapid development of the epidemic within a crop and the spread of the disease to other crops and areas. Again, wet conditions are necessary for spore production and infection. Strong winds are needed to spread the disease any great distance.

Severe yellow spot may result in short, spindly plants with reduced tillering and root development. Where conditions are favourable, plants may be fully defoliated soon after flowering.

Grain yield can be substantially reduced and losses of >50% may occur in extreme situations. Pink grain with reduced value is also a frequent result of severe epidemics of yellow spot. Where wheat follows wheat and some stubble is left on the soil surface, losses may be around 10–15%, and up to 30% in wet seasons.

### *Management*

Yellow spot is likely to develop in wet years in fields where wheat residues remain on the soil surface. The impact of the disease can be reduced by:

- planting partially resistant varieties
- rotation with resistant crops such as barley, oats or chickpeas
- incorporation of stubble into the soil
- grazing or burning the stubble late in the fallow period

Varieties partially resistant to yellow spot offer the only long-term solution and they should be considered for planting where yellow spot could be a problem.

### *Fungicide management*

Fungicides and fungicide combinations used against yellow spot in Australia include:

- propiconazole
- tebuconazole
- azoxystrobin + cyproconazole
- propiconazole + cyproconazole

Timing for applying the chosen fungicide is crucial, and growers can use short-term weather forecasts to assist in the timing of fungicide applications. The most effective time of application is at 90% flag leaf emergence with disease levels of <10% on the flag leaf.

The time between infection and appearance of symptoms is termed the latent period, and this is a short time in tan spot.

The higher rate of application has been shown to provide longer protection under periods of high disease pressure. Fungicide efficacy is greater on susceptible varieties and is reduced with increasing levels of resistance.

Information on fungicide efficacy has been gathered from irrigated field trials and it does not confirm the economic viability of such applications during the extreme pressure of large-scale epidemics.<sup>24</sup>

### *Make management decisions at or before sowing*

- Avoid sowing wheat-on-wheat.
- However, if you do plan to sow wheat-on-wheat, consider a late (autumn) stubble burn. Burning, depending on completeness, eliminates the wheat stubble harbouring the yellow spot fungus. A late pre-sow burn, even though cooler, is still preferable to an earlier, hotter burn due to considerations of soil moisture storage and erosion risk. Cultivation is less advisable, because stubble can remain on the soil surface, carrying yellow spot inoculum. Cultivation dries out the soil where you are planning to establish your next crop; it reduces water infiltration into the soil (in fallow and throughout season); and it evenly spreads another stubble-borne wheat pathogen, crown rot, across the paddock, distributing it through the soil cultivation layer where it can access the main infection sites in the following cereal crops.
- Select a wheat variety with some level of resistance to yellow spot (note tolerance–resistance to other diseases though, especially *Pratylenchus thornei*).

Primary management decisions for yellow spot need to be made prior to and/or at sowing. Fungicides are a poor last resort for managing yellow spot, because they have reduced efficacy against this leaf disease.<sup>25</sup>

## 9.6.8 Barley yellow dwarf virus

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.<sup>26</sup>

### *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.

<sup>24</sup> 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>

<sup>25</sup> S Simpfendorfer (2013) Management of yellow spot in wheat: decide before you sow. GRDC Update Papers, 5 March 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Management-of-yellow-spot-in-wheat-decide-before-you-sow>

<sup>26</sup> GRDC (2013) Management tips to avoid yield penalties. Southern Region. Barley Yellow Dwarf Virus Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-BYDV>

The virus 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 different species of aphids transfer different types of BYDV. However, in the southern grain-growing region, the most common species include 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.<sup>27</sup>

### Symptoms

Symptoms of BYDV infection may take at least 3 weeks to appear. When assessing a paddock for an outbreak, growers should look for:

- Sporadic patches of plants that have turned yellow, red or purple, 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, then they are likely to attack plants near fencelines first.
- Aphids located on the crown and lower stem, then leaves.

BYDV symptoms vary with the crop and include:

- Wheat: leaves may show a range of symptoms including a slight mottling to bright yellow colour. Leaves first turn yellow at the tip, with the colour extending down the base in a dappled pattern (Figure 8). There may be streaks of red to purple at the tip. An infection before tillering can lead to stunted growth, sterility and reduced grainfill.

If left untreated, damage will radiate outwards as wingless juvenile aphids crawl to the next plant to feed, spreading the virus.<sup>28</sup>



Figure 8: A wheat leaf damaged by BYDV. The leaf shows yellowing at the tip with the colour extending down the base plus streaks of purple. (Photo. Hugh Wallwork, SARDI)

<sup>27</sup> 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>

<sup>28</sup> 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>

### Yield loss

All early BYDV infections of cereal plants will mean they have 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 by Trent Potter in the South East of South Australia 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 losses due to BYDV have occurred, trial results have shown no difference in protein content between sprayed and untreated plots.<sup>29</sup>

### 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, then 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.<sup>30</sup>

### 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.<sup>31</sup>

### Management

For grain growers who decide to manage aphids, it is critical to have a control strategy and put it in place before sowing starts. Do not wait until aphids are found, because infection or damage will have already occurred.

<sup>29</sup> 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>

<sup>30</sup> 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>

<sup>31</sup> 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>

## More information

[Australian Pesticides and Veterinary Medicines Authority](#)

Growers in high-risk areas should treat each year as a 'BYDV year' unless there has been low rainfall over summer and autumn.<sup>32</sup>

### 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.<sup>33</sup>

### Insecticides

Growers must work to prevent the spread of BYDV early after crop emergence, when plants are most vulnerable.

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.<sup>34</sup>

### BYDV resistance

There is some level of resistance to BYDV in cereals. Some wheats are highly susceptible (e.g. Brennan<sup>(1)</sup>), whereas others have some resistance. CSIRO researchers have found a source of BYDV resistance and used it in Mackellar<sup>(1)</sup> winter wheat. No yield losses were observed in BYDV infection trials with Mackellar<sup>(1)</sup> wheat.<sup>35</sup>

### 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 may coincide with peak spring flights of aphids, resulting in more severe damage.<sup>36</sup>

<sup>32</sup> 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>

<sup>33</sup> 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>

<sup>34</sup> 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>

<sup>35</sup> 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>

<sup>36</sup> 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>

## More information

Cereal Leaf and Stem Diseases (2000 Edition) (GRDC012) GRDC Bookshop Free Phone: 1800 110044 Email: [ground-cover-direct@canprint.com.au](mailto:ground-cover-direct@canprint.com.au); also available from the National Library of Australia

[Agriculture Victoria Notes: Barley yellow dwarf virus](#)

[Agriculture Victoria: Victorian winter crop summary](#)

[GRDC Fact Sheets: Barley yellow dwarf virus](#)

[MFMG: Wheat agronomy trials](#)

[PIRSA: Cereal seed treatments](#)

## 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. On top of summer weed control, spraying out perennial grasses near and around cereal paddocks at least 3 weeks before sowing may reduce aphid numbers.<sup>37</sup>

### 9.6.9 Eyespot

Eyespot is a fungal disease caused by *Oculimacula yallundae* (*Tapesia yallundae*). The fungus infects the lower stems of wheat plants, resulting in stem breakage, lodging, yield loss and high screenings.

The fungus requires rain to splash spores from the stubble and prolonged moisture or high humidity at the stem base to allow infection to occur. For these reasons, the disease is more prevalent where wheat is grown in medium–high-rainfall areas.

Eyespot has been an occasional problem in south-eastern Australia for at least 30 years. It was most commonly found where tall wheat varieties were grown for hay and where rotations were short.<sup>38</sup> Eyespot has increased in importance on the Lower Eyre Peninsula and on the Adelaide Plains over the last 2–3 years and is being detected in the South-East.

Eyespot is favoured by high rainfall, thick crops to maintain humidity, close rotations and stubble retention.

Inoculum survives in stubble for up to 2 years and infects the lower stems. Damage is mainly caused by lodging, which is more likely to occur in taller varieties and varieties with weaker stems. Lodging typically occurs in all directions because stems break according to where the fungal lesion occurs. This makes the crop more difficult to harvest. Losses can also occur from reductions in head numbers and grain size.

Symptoms include greyish, eye-shaped lesions (usually difficult to detect until stem elongation) at the bases of stems and lodging during grainfill (Figure 9).

Conditions in 2014 were ideal for eyespot development, with rain and high humidity during tillering and stem elongation. Growers should consider protective sprays at GS31 in paddocks where eyespot inoculum has been observed in the past 2 years.

No fungicides are currently registered for use against eyespot in Australia. Growth regulants can help to reduce lodging.

Research funded by GRDC is assessing varietal resistance and fungicide efficacy for managing this disease.<sup>39</sup>

<sup>37</sup> 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>

<sup>38</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

<sup>39</sup> H Wallwork, M Evans (2014) Cereal disease update—net blotch, eyespot, wheat streak mosaic virus and white grain. GRDC Update Papers, 20 August 2014, <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Cereal-disease-update-net-blotch-eyespot-wheat-streak-mosaic-virus-and-white-grain>



*Figure 9: Eyespot, named for its eye-shaped lesion at the base of wheat stems, is a fungal disease infecting crops in South Australia's Mid North, Lower Eyre Peninsula and South East as well as Tasmania, Victoria's Western District and parts of the New South Wales Riverina. (Photo. Hugh Wallwork, SARDI)*

Infection has been on the rise in recent years, due to shorter rotations and retention of stubbles and because early sowing and increased use of nitrogen (N) has led to denser crop canopies.

In many cases, plants lodge in all directions with each stem falling according to the side where the fungal lesion has weakened the stem (Figure 10). This results in a tangled mass of plants that is hard to lift during harvest.



*Figure 10: Lodging that occurs due to eyespot results in stems laying in random directions, compared with lodging from wind and rain in which stems tend to lay in one direction. (Photo: Mick Faulkner, Agrilink Agricultural Consultants)*



If left untreated, eyespot can result in yield losses of >50% through damage from lodging, high screenings, smaller grain and grain loss.

Eyespot tends to be more devastating in years of high production, where there is more moisture and rainfall during vegetative growth leading up to and around GS30. Yield losses are higher and smaller grains more common in high production years.<sup>40</sup>

### Symptoms

Eyespot lesions weaken the stem, which is frequently kinked or broken at the mid-point of the lesion (Figure 11). To see the eyespot clearly, strip back the leaf sheath to reveal the bare stem. A sooty mould should be apparent around the area of stem damage.

Young eyespot lesions are brown but turn a more bleached white on older stems. Older lesions can surround the entire stem and be up to 4 cm long. The lesion blocks the plant's vascular system, restricting plant growth and grain filling. Lesions also weaken the outer cell walls of the stem.<sup>41</sup>



Figure 11: Eyespot lesions weaken the stem, which is frequently kinked or broken at the mid-point of the lesion. A sooty mould is present around the area of stem damage. (Photo: Hugh Wallwork, SARDI)

### Life cycle

The eyespot fungus can survive in plant stubbles for  $\geq 2$  years if the stubbles have not broken down. Fungal spores produced on the stubbles are rain-splashed over short distances in autumn and winter. Infection of leaf sheaths occurs when moisture levels

<sup>40</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

<sup>41</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

remain high for extended periods. The early stages of infection cannot be detected visually. Lesions can only be detected after 6–8 weeks on stems, and by then, it will be too late to avoid yield losses.

The eyespot fungus does have a sexual stage, which takes the form of a tiny cup fungus on stubbles. These fruiting bodies produce airborne spores, which allow the fungus to spread over long distances. These cup fungi are not easily observed in the field but they help to explain the disease's distribution.<sup>42</sup>

### Risk factors

The key risk factors for eyespot damage include:

- previous infection in a paddock and the presence of cereal and grass stubbles
- receiving frequent rain and long periods of moist conditions to allow spores to spread and infect plants during early growth stages
- sowing wheat varieties that are tall and/or have weak stems, making them more likely to lodge when infected
- lush crops with closed canopies that keep the base of the plant wet
- high rates of application of N fertiliser<sup>43</sup>

### Variety choice

Useful resistance has been bred into some northern European varieties; however, it is not a priority in Australian breeding programs and resistance has not been assessed. There are anecdotal reports that some varieties may be more resistant than others, although most variation is likely to be related to plant height and straw strength.

Losses have not been detected in durum wheat but research is yet to determine whether that is because the crop has some level of resistance or whether there has been reduced disease pressure because of the rotations used for durum wheat.<sup>44</sup>

### Management issues

Eyespot is a difficult disease to manage because infection is hard to identify for early treatment. Unlike rust (a communal disease), eyespot is a property-by-property disease. Different rotations, farming practices and environmental conditions can make the difference between infection and healthy crops.

Management must focus on preventative measures. Grain growers need to anticipate how often conditions conducive to eyespot occur on their property. This means the frequency of rainfall of ~3 mm/day for several days in July and early August, combined with days when humidity is high at the base of the plant.<sup>45</sup>

### Chemical treatments

No chemical options are registered for treatment of eyespot in Australia, but the GRDC and private industry are funding research into a range of chemical products to determine their activity against eyespot.

Growth regulants can be used to shorten and strengthen plant stems and thus reduce the risk of infected plants lodging.<sup>46</sup>

<sup>42</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

<sup>43</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

<sup>44</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

<sup>45</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

<sup>46</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

### Cultural options

Various practices influence the risk of eyespot infection.

#### Stubble

Modern farming practices involve retaining more standing stubble. Thick stubble that stands 10–20 cm high affects the environment around the base of subsequent crops. Wheat in standing stubble will have a higher risk of infection. Burning stubble can reduce inoculum but does not eliminate the disease.

#### Rotation

Reducing the frequency of growing wheat reduces eyespot infection. Although the fungus can survive in stubble for  $\geq 2$  years, the amount of inoculum will be reduced with each year out of wheat. Barley has not been observed to lodge, but it can be infected and thereby help the fungus to survive.

#### Nitrogen timing

The development and severity of the disease depends on moisture at the stem base; therefore, keeping the canopy open for as long as possible can help to reduce risk of eyespot infection. This would mean a later rather than early application of N to avoid promoting excessive canopy growth at GS30–32.

#### Seeding rate

Higher seeding rates tend to create a denser canopy earlier in the season. Although it is not a large risk, when added to the other infection factors, it could be a factor.

#### Time of sowing

Early sowing tends to create crops with more biomass and this increases the risk of eyespot. However, the yield losses from delaying sowing could outweigh the potential losses from eyespot. Other control options should be used in preference.<sup>47</sup>

## 9.6.10 Powdery mildew

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 needed to maintain this situation to minimise the risk of the pathogen developing into a threat to the industry.<sup>48</sup>

### Disease life cycle

Wheat powdery mildew is a fungal disease caused by *Blumeria graminis* f. sp. *tritici*, whereas barley powdery mildew is caused by *B. 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 12). These colonies produce windborne spores that spread the disease during the growing season (Figure 13).

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.<sup>49</sup>

<sup>47</sup> GRDC (2013) Eyespot in medium and high rainfall zones. Southern Region. Eyespot in Wheat Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-Eyespot-Wheat>

<sup>48</sup> GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat>

<sup>49</sup> GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat>

### More information

[GRDC Fact Sheets: Eyespot in wheat](#)

[GRDC Update Papers: Cereal disease update—net blotch, eyespot, wheat streak mosaic virus and- white grain](#)



*Figure 12: 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)*



*Figure 13: 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 >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

Historically, powdery mildew has been less common in wheat, but it has been causing damage for several years on the Lower Eyre Peninsula and in other areas where the susceptible variety Wyalkatchem<sup>†</sup> was widely grown.

It also occurs where thick crops allow high humidity to be maintained over extended periods.<sup>50</sup>

### 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.<sup>51</sup>

### 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 that are 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.<sup>52</sup>

<sup>50</sup> GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat>

<sup>51</sup> GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat>

<sup>52</sup> GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat>

### *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.

Wheat crops are best treated with in-furrow fungicides because seed treatments may shorten coleoptiles and cause emergence problems.

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 than that used at seeding or used previously as a spray. Always use recommended label rates. This will help to reduce the risk of fungicide resistance developing.

A good option is a QoI–DMI (quinone outside inhibitor–demethylation inhibitor) mix for the first foliar spray and a DMI for the second.

### *Fungicide resistance in the Southern Region*

In Western Australia, resistance in powdery mildew populations in barley to some of the older fungicides has already developed. 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.<sup>53</sup> Similar changes are likely to occur in eastern Australia.

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 14) and instead consider triazole fungicides such as epoxiconazole, prothioconazole, propiconazole or cyproconazole.

The Group 11 QoIs such as azoxystrobin and pyraclostrobin can also be used in combination with triazoles. Experience in Europe shows that the Group 11 QoIs can lose their effectiveness very quickly if used alone.<sup>54</sup>

## **i** More information

[Australian Pesticides and Veterinary Medicines Authority](#)

<sup>53</sup> GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat>

<sup>54</sup> GRDC (2014) Powdery mildew in barley and wheat. Southern Region. Barley Powdery Mildew Fact Sheet, GRDC, <http://www.grdc.com.au/GRDC-FS-PowderyMildewBarleyWheat>

### More information

[Agriculture Victoria](#)  
[Notes: Wheat disease management in the Wimmera](#)



Figure 14: 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)

#### 9.6.11 Wheat streak mosaic virus

Wheat plants infected with WSMV have discontinuous, yellow-streaked and mottled leaves (Figure 15). Plants infected before tillering are often stunted, discoloured and rosetted. The host range of WSMV is wheat, barley, oats, rye, maize and some grass species including brome grass, barley grass, ryegrass, phalaris and liverseed grass. In Australia, the virus has been found on wheat, *Setaria* and *Urochloa*.



Figure 15: Symptoms of Wheat streak mosaic virus in a young wheat plant. (Photo: CSIRO)

## More information

[GRDC: Wheat streak virus](#)

[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](#)

WSMV cannot spread without the aid of a vector to transmit it from a diseased plant to a healthy plant. The wheat curl mite (*Aceria tosichella*) is the vector for WSMV. Wheat curl mites are ~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 cannot survive outside a host plant or the vector. Therefore, between summer harvest and planting of the next wheat crop, WSMV persists in the 'green bridge' of volunteer wheat plants and other grasses.

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

This means that any green plant material should be dead at least 2 weeks before sowing the next wheat crop.<sup>55</sup>

## 9.7 Root and crown diseases

Most cereal root and crown diseases (take-all, crown rot, cereal cyst nematode and root-lesion nematode, RLN) 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.<sup>56</sup>

Wheat can incur root and crown diseases, including:

- take-all
- crown rot
- *Pythium*
- *Rhizoctonia*
- cereal-cyst nematode (CCN)
- RLN (*Pratylenchus*) (see [GrowNotes Wheat South Section 8. Nematodes](#))
- common root rot

### 9.7.1 Take-all

Take-all is a soilborne disease of cereal crops and is most severe on wheat crops throughout southern Australia. The disease is caused by two variants of the fungus *Gaeumannomyces graminis* var. *tritici* (Ggt) and is most severe in the high-rainfall areas of the agricultural region (i.e. southern cropping regions and areas closer to the coast). 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 to 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

<sup>55</sup> 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>

<sup>56</sup> 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](http://agriculture.vic.gov.au/_data/assets/pdf_file/0007/252664/Vic-Cereal-Disease-Guide-AG1160-Feb-2015-V2.pdf)



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 of stunting 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 16). 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.

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.<sup>57</sup>

For images and detailed information on identifying cereal root and crown diseases, see the [GRDC Cereal root and crown diseases: Back Pocket Guide](#).



*Figure 16: 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. Take-all causes a blackening of the sub-crown internodes, and primary and secondary roots. Take-all 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. The fungus can also cause darkening of crowns when severe. (Source: GRDC Cereal and root and crown diseases: The Back Pocket Guide)*

<sup>57</sup> GRDC (2014) Take-all. GRDC Media Centre, 26 June 2014, <http://grdc.com.au/Media-Centre/Hot-Topics/Take-all>

### 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 only decreases 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.

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 due to 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. The ammonium form of nitrogenous fertiliser reduces take-all.

### 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.

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.<sup>58</sup>

#### 9.7.2 Crown rot

Crown rot is caused predominantly by the fungus *Fusarium pseudograminearum*. Crown rot affects wheat, barley and triticale.<sup>59</sup> 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.<sup>60</sup>

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.

### More information

[Soil Quality Fact Sheets: Take-all disease](#)

### More information

[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](#)

<sup>58</sup> GRDC (2014) Take-all. GRDC Media Centre, 26 June 2014, <http://grdc.com.au/Media-Centre/Hot-Topics/Take-all>

<sup>59</sup> 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>

<sup>60</sup> 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>

## **i** More information

[GRDC Update Papers: Crown rot: be aware of the balancing act or the fall may be harder](#)

## **▶** GRDC Video

[GRDC video: Crown rot—it's all a balancing act](#)

### *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.

Some of the newer wheat varieties appear promising in that they provide improved tolerance to both crown rot and the RLN *Pratylenchus thornei*.

### *Symptoms*

- Tiller bases are always brown, often extending up 2–4 nodes.
- Some tillers on diseased plants may not be infected.
- Whitehead formation is most severe in seasons with a wet start and dry finish.
- Plants often break off near ground level when pulled up.
- Plants are easy to pull up in good moisture situations because they have little root structure.
- Cottony fungal growth may be found inside tillers.
- Pinkish fungal growth may form on lower nodes, especially during moist weather.
- Pinched grain is observed at harvest.<sup>61</sup>

Infection is characterised by a light honey-brown to dark brown discoloration of the base of infected tillers (Figure 17). 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.<sup>62</sup>



Figure 17: Basal browning indicating crown rot infection.

<sup>61</sup> K Moore, B Manning, S Simpfendorfer, A Verrell (2005) Root and crown diseases of wheat and barley in northern NSW. NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0019/159031/root-crown-rot-diseases.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/159031/root-crown-rot-diseases.pdf)

<sup>62</sup> 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>

## **i** More information

[NSW DPI: Northern grains region trial results. Autumn 2013. Impact of sowing time on crown rot in barley, bread and durum wheat—Walgett 2012 \(pp. 24–26\)](#)

[GRDC Ground Cover: Seedborne fusarium tests crown rot strategies](#)

### *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.<sup>63</sup>

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:

- **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. 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 18) 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.<sup>64</sup>

<sup>63</sup> UNE Agronomy of Grains Production course notes.

<sup>64</sup> S Sumpfendorfer, M Gardner (2013) Crown rot: be aware of the balancing act or the fall may be harder. GRDC Grains Update Papers, 25 February 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Crown-rot-be-aware-of-the-balancing-act-or-the-fall-may-be-harder>

## **i** More information

[extensionAUS: Crown rot in winter cereals](#)

[Research paper: Monitoring fusarium crown rot populations in spring wheat residues using quantitative real-time polymerase chain reaction](#)

[Research paper: Decomposition and chemical composition of cereal straw](#)



Figure 18: 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.

## Management

Managing crown rot requires a three-pronged attack:

1. Rotate crops.
2. Observe plants for basal browning.
3. Test stubble and/or soil.

## **i** More information

[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](#)

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.<sup>65</sup>
- 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

<sup>65</sup> GRDC (2011) Stop the rot: rotate, observe, test. GRDC Media Centre, 22 February 2011, <http://www.grdc.com.au/Media-Centre/Media-News/National/2011/02/Stop-the-crown-rot-Rotate-Observe-Test>

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 RLN.

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.<sup>66</sup>

The effect of previous crops on the incidence and severity of crown rot and yield of wheat was investigated in field studies in the Wimmera (Victoria) and in northern New South Wales. Evidence was sought for enhanced suppression of crown rot following *Brassica* break crops compared with other non-host rotation crops, as has been demonstrated for take-all.

Yield was lower after cereals than after broadleaf break crops and was higher after brassicas than after chickpeas. In the crown-rot-susceptible durum wheat, the yield response to previous crops was closely associated with the levels of crown rot infection.

In the tolerant bread wheat, the response to previous crops was similar to that of durum wheat despite lower disease levels and a weaker association with some of the disease measurements. No other explanation for the impacts of previous crops was obvious.

The results indicate that *Brassica* break crops may be more effective than chickpeas in reducing crown rot infection of following crops, and tolerant varieties of wheat can suffer yield penalties in the absence of visible symptoms such as whiteheads.<sup>67</sup>

### 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 is not a tool to enable back-to-back wheat production under moderate–high risk of crown rot.
- Inter-row sowing will provide best benefit by incorporation into a crown rot disease-management package based on sound crop rotation.<sup>68</sup>

### Stubble burning

Burning removes the aboveground portion of crown rot inoculum but the fungus will still survive in infected crown tissue belowground; therefore, stubble burning is not a 'quick fix' for high-inoculum situations. Removal of stubble residues through burning will increase evaporation from the soil surface and affect fallow efficiency. A 'cooler' autumn burn is therefore preferable to an earlier 'hotter' burn because it minimises the negative impacts on soil moisture storage while still reducing inoculum levels.

### 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.

<sup>66</sup> K Moore, B Manning, S Simpfendorfer, A Verrell (2005) Root and crown diseases of wheat and barley in northern NSW. NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0019/159031/root-crown-rot-diseases.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0019/159031/root-crown-rot-diseases.pdf)

<sup>67</sup> J Kirkegaard *et al.* (2003) Effect of previous wheat crops on crown rot infection and yield of wheat. Australian Agronomy Conference. Australian Society of Agronomy/The Regional Institute Ltd, <http://www.regional.org.au/au/asa/2003/c/6/kirkegaard.htm>

<sup>68</sup> G Rummery, R Daniel, S Simpfendorfer (2007) Inter-row crown rot management—the results are in. Northern Grower Alliance, <http://www.nga.org.au/results-and-publications/download/42/australian-grain-articles/diseases-1/crown-rot-inter-row-sowing-results-march-2007-.pdf>

## More information

[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 Video

[GRDC GCTV9: Crown rot & root lesion nematodes](#)

## GRDC Podcast

[GRDC Podcasts: Crown rot, root disease and WeedSmart](#)

## More information

[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](#)

## **i** More information

[GRDC Update Papers: Crown rot tolerance levels in current and future cultivars](#)

[GRDC Fact Sheets: Wheat breeding](#)

[GRDC Update Papers: Root lesion nematode and crown rot—double trouble](#)

[GRDC Fact Sheets: Cracking wheats toughest nuts](#)

## **▶** GRDC Video

[GRDC Video: Crown rot tolerance levels in current and future cultivars](#)

Details on crown rot resistance or tolerance ratings among bread wheats can be found in the annual [NSW Winter crop variety sowing guide](#), [National Variety Trials \(NVT\) website](#), the [NVT Queensland wheat variety guide](#), [NVT Victorian winter crop summary 2015](#), and [South Australian sowing guide 2015](#).

For more information see: [GrowNotes Wheat South Section 8. Nematodes](#).

### 9.7.3 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 19). Affected plants occur in patches where soil is wetter.

Seedlings are pale and stunted (Figure 20). Older plants have fewer tillers and may rot and die. Roots are stunted, short and stubby with few laterals (Figure 21). Root tips often water soaked and develop a soft yellow to light brown rot.



Figure 19: Symptoms of Pythium root rot: patches of poor growth.



Figure 20: Symptoms of Pythium root rot: seedlings are pale and stunted.



Figure 21: Symptoms of *Pythium* root rot: 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.

Like *Pythium* root rot, waterlogging in cereals causes stunted plants with dead or dying roots. 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.<sup>69</sup>

## 9.7.4 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 22) 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 23). 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.<sup>70</sup>

<sup>69</sup> 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>

<sup>70</sup> GRDC (2016) Rhizoctonia. Southern Region. GRDC Tips and Tactics.





Figure 22: Aboveground symptoms of crop unevenness (left panel) are seen when *Rhizoctonia* damages crown roots, even when seminal roots escape the infection (right panel).



Figure 23: Symptoms of *Rhizoctonia* disease: left: healthy roots; middle: seedling severely infected; right, crown root fully infected. (Photos: Sjaan Davey)

### 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.

#### 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. Trials across the lower rainfall cropping region of southern Australia have indicated that grass-free 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 build-up 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 has shown 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 root-health 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 cm.

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. <sup>71</sup>

Table 5 presents a management sequence to deal with *Rhizoctonia* disease in cereal crops.

<sup>71</sup> GRDC (2016) *Rhizoctonia*. Southern Region. GRDC Tips and Tactics.

Table 5: Management of *Rhizoctonia* disease in cereal crops.

Year 1 crop (Sept-Nov)	Summer (Dec-April)	Season break (April-May)	Year 2 crop (May-August)
<i>Check for inoculum build-up</i>	<i>Facilitate inoculum decline</i>	<i>Select appropriate crop</i>	<i>Manage infection and disease impact through management practices</i>
<ul style="list-style-type: none"> <li>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 <i>Rhizoctonia</i> disease</li> </ul>	<ul style="list-style-type: none"> <li>In wet summers, early weed control will reduce inoculum. In dry summers, inoculum levels do not change</li> <li>Adopt practices that prolong soil moisture in the upper layers (e.g. stubble retention and no cultivation) which helps maintain higher microbial activity</li> <li>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</li> </ul>	<ul style="list-style-type: none"> <li>Select a non-cereal crop (e.g. canola or pulses) if you want to reduce inoculum levels</li> <li>Remove autumn ‘green bridge’ before seeding with good weed control</li> </ul>	<ul style="list-style-type: none"> <li>Sow early; early-sown crops have a greater chance of escaping infection</li> <li>Use soil openers that disturb soil below the seed to facilitate root growth – knife points reduce disease risk compared to discs</li> <li>Avoid pre-sowing SU herbicides,</li> <li>Supply adequate nutrition (N, P and trace elements) to encourage healthy seedling growth</li> <li>Avoid stubble incorporation at sowing to minimize N deficiency in seedlings</li> <li>Consider seed dressings and banding fungicides to reduce yield loss</li> <li>Remove grassy weeds early</li> <li>Apply nutrient/trace elements, foliar in crop, if required</li> </ul>

### More information

[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](#)

## 9.7.5 Disease identification

### *Identifying risk*

PreDicta B is a unique, DNA-based service that identifies soilborne pathogens such as *Rhizoctonia* so that cropping programs can be adjusted before seeding to include strategies to minimise soilborne risk.

Paddocks at high risk of *Rhizoctonia* disease can also be identified by examining crown roots of cereals in areas of poor growth (not necessarily bare patches) in the previous spring.

### *Bare patches*

Severe seedling infection causes patches of poor crop growth from very small to several metres across (Figure 24). This can occur in cold or dry soils and conditions that restrict seminal root growth (e.g. compaction, lack of moisture, herbicide residues).

### *Uneven growth at tillering*

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 24: *Rhizoctonia* infection of seminal roots results in distinct patches of poor growth. (Photo: Gupta Vadakattu)

### 9.7.6 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'.<sup>72</sup>

#### 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.

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.<sup>73, 74</sup>

#### 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.

<sup>72</sup> GRDC (2016) Rhizoctonia. Southern Region. GRDC Tips and Tactics.

<sup>73</sup> GRDC (2016) Rhizoctonia. Southern Region. GRDC Tips and Tactics.

<sup>74</sup> GRDC (2015) Rhizoctonia. Western Region. GRDC Tips and Tactics, <https://www.grdc.com.au/Resources/Factsheets/2015/11/Rhizoctonia-Western-Region>

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 25).

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, are 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.<sup>75</sup>

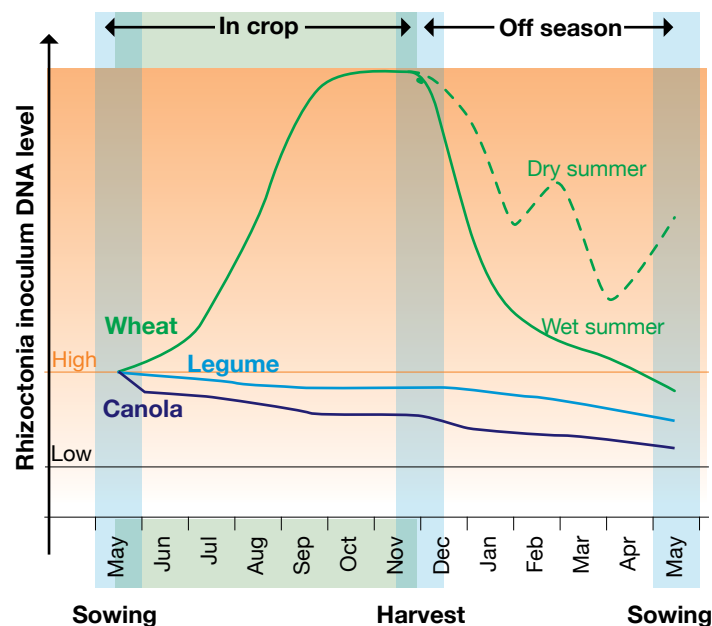


Figure 25: *Rhizoctonia solani* AG8 inoculum in soil build up in-crop and decline during summer following rainfall under wheat. By comparison, inoculum levels decline in-crop under grass-free canola and legume crops.

### 9.7.7 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 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.

<sup>75</sup> GRDC (2016) Rhizoctonia. Southern Region. GRDC Tips and Tactics.

## **i** More information

[GRDC: Cereal root and crown diseases. The Back Pocket Guide](#)

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.

### 9.7.8 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*

This disease affects mature wheat ears. A mass of black fungal spores replaces the interior of the grain and forms a bunt ball. Infected plants are shorter and have darker green ears than healthy plants, and gaping glumes. Bunt is usually only noticed at harvest, when bunt balls and fragments are seen in the grain. Grain deliveries with traces of bunt balls are not accepted by AWB Ltd.

If a bunt ball is crushed, a putrid fish-like odour is released. Spores released during harvest contaminate sound grain. The spores germinate with the seed when planted and infect the young seedling. The fungus then grows inside the developing wheat plant, finally replacing each normal grain with a mass of spores.

Bunt control recommendations:

- Seed that is sown to provide the following season's wheat seed should be treated with a fungicidal seed dressing.
- Seed obtained from plants grown from untreated seed should be treated with a fungicidal seed dressing before planting.
- Grain from a crop with bunt should not be used for seed.
- On farms where a crop has been affected by bunt, all wheat seed should be treated with fungicidal seed dressing for at least 6 years.

These recommendations could be adopted in one of two ways:

- Treat all wheat seed with a fungicidal seed dressing every second year.
- Treat a small quantity of seed of each variety with a fungicidal seed dressing every year and use the grain from this as planting seed in the following year.<sup>76</sup>

#### *Loose smut*

Loose smut is a fungal disease that becomes evident at head emergence. A loose, powdery mass of fungal spores is formed in the head; these spores are readily blown away leaving a bare, ragged stalk.

If the spores settle on healthy flowers, they may germinate and infect the embryo of the developing seed. When this seed is planted, the smut grows inside the plant until flowering, when the disease appears. Because loose smut is carried inside the seed, systemic seed dressings are needed to control it. These are more expensive than the other treatments and should only be used when a high incidence of loose smut is expected.<sup>77</sup>

<sup>76</sup> 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>

<sup>77</sup> 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>

## SECTION 10

# Plant growth regulators and canopy management

## **i** More information

[Sustainable Farming Systems: Crop management in wheat](#)

[Southern Farming Systems: Canopy management disease control interaction in wheat](#)

[Southern Farming Systems: Maximising water use efficiency in the HRZ through canopy management](#)

[Southern Farming Systems: Comparing different nitrogen products for yield and grain quality responses in wheat](#)

## 10.1 What is canopy management?

Canopy management deals with the green surface area of the crop canopy in order 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.<sup>1</sup>

The concept of canopy management was primarily developed in Europe and New Zealand—both distinct production environments from those typically found in most grain-producing regions of Australia and especially the southern grains region.

Canopy management includes a range of crop-management tools for crop growth and development, to maintain canopy size and duration and thereby optimise photosynthetic capacity and grain production. One of the main tools for growers to manage the crop canopy is the rate and timing of applied fertiliser nitrogen (N).

The main difference between canopy management and previous N-topdressing research is that all or part of the N input is tactically delayed until later in the growing season. This delay tends to reduce early crop canopy size but the canopy is maintained for longer, as measured by green leaf retention, during the grain-filling period.<sup>2</sup>

### 10.1.1 Canopy management in a nutshell

Select a target head density for your environment; 350–400 heads/m<sup>2</sup> should be sufficient to achieve optimum yield, even for yield potential of 4–5t/ha.

Adjust canopy management based on paddock nutrition, history and seeding time to achieve target head density.

Established plant populations for wheat between 75 and 250 plants/m<sup>2</sup> would cover most scenarios:

- Use the lower end of range (75–100 plants/m<sup>2</sup>) for earlier sowings–high fertility and/or environments with low yield potential and low rainfall.
- Use the higher end of the range (150–250 plants/m<sup>2</sup>) for later sowings, lower fertility situations and/or higher rainfall regions.

During stem elongation (Zadoks growth stages GS30–39), provide the crop with

<sup>1</sup> N Poole (2005) Cereal growth stages. GRDC, <http://www.grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf>

<sup>2</sup> G McMullen (2009) Canopy management in the northern grains region—the research view. Northern Grower Alliance, Consultants Corner, Australian Grain, 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>

## **i** More information

[GRDC: Advancing the management of crop canopies](#)

[GRDC/Grassroots Agronomy: Assessing canopy management in CTF systems](#)

[GRDC Ground Cover: New tool lifts canopy management potential](#)

[GRDC: Disease management and crop canopies](#)

[NSW DPI: Durum wheat and barley canopy management](#)

necessary nutrition (particularly N at GS30–33 pseudostem erect–third node), matched to water supply and fungicides to:

- maximise potential grain size and grain number per head;
- maximise transpiration efficiency;
- ensure complete radiation interception from when the flag leaf has emerged (GS39); and
- keep the canopy green for as long as possible following anthesis.

Keeping tiller numbers just high enough to achieve potential yield will help to preserve water for filling grain and increase the proportion of water-soluble carbohydrates (WSC).

The timing of the applied N during the GS30–33 window can be adjusted to take account of target head number. Earlier applications in the window (GS30) can be employed where tiller numbers and soil N seem deficient for the desired head number. Conversely, where tiller numbers are high and crops are still regarded as too thick, N can be delayed further until the second or third node (GS32–33), which will result in fewer tillers surviving to produce a head.<sup>3</sup>

## 10.2 Key cereal growth stages for disease control and canopy management

### 10.2.1 Why is growth stage important in making fungicide decisions?

Five to 10 years ago, it was common to make decisions on fungicide applications for stripe rust based on thresholds of infection; these thresholds varied from 1% to 5% plants infected. However, growers and advisers found that, in the paddock, it was difficult to calculate whether 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.

Trials on stripe rust control (GRDC project SFS00006-2002–04) quickly established that foliar fungicide applications based on growth stages and applied between second node (GS32) and flag-leaf emergence (GS39), or at both stages, gave good control of the disease. These timings based on growth stage also gave growers the opportunity to plan disease management strategies for susceptible cultivars.<sup>4</sup>

### 10.2.2 Why do these growth-stage timings work for stripe rust control?

The primary reason for these timings working is that the growth stages between GS32 and GS39 coincide with the emergence of the top three leaves of the crop canopy in wheat, meaning that fungicides are applied to leaves shortly after they have emerged and before tissue becomes heavily infected. However, it is also important to note that foliar fungicide applied at first or second node (GS31–32) does not protect the flag leaf or the leaf beneath it (flag-1), because they have not emerged at this early stem-elongation growth stage. Equally, a foliar fungicide applied at flag leaf (GS39) may

<sup>3</sup> N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, <http://www.grdc.com.au/CanopyManagementGuide>

<sup>4</sup> N Poole (2011) Cereal growth stages and decision making for fungicide timing. GRDC Update Papers, 7 Sept. 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Cereal-growth-stages-and-decision-making-for-fungicide-timing>



protect the flag leaf but may be too late to protect flag-2, which emerged 2–3 weeks earlier.<sup>5</sup>

### *Yield loss to disease at different growth stages of disease onset*

Although the use of growth-stage timings for fungicide applications can ensure that the top three leaves of the plant are adequately protected, the growth stage of disease onset dictates the level of economic response to a fungicide.

For the construction of the RustMan model, a simple relationship (derived from trial results) linked expected yield losses to the onset of stripe rust infection at particular growth stages (Table 1). This chart (although complicated by the presence of adult plant resistance, APR) remains a useful guide to potential yield loss with susceptible cultivars at different growth stages. It is based on the premise that yield loss to stripe rust is dependent on:

- the extent of stripe rust by early grain development
- the temperature during grainfill

Responses in Table 1 assume average temperatures; if hotter, the yield loss (due to disease) is less than expected.

Table 1: Expected yield losses (%) from stripe rust based on different growth stages of disease onset

Source: ICAN Cereal Foliar Disease Workshops for Advisers (G. Murray, July 2004)

Disease onset		Stripe rust reaction			
Growth Stage		Susceptible	Moderately susceptible	Moderately resistant	Resistant
GS31	First node	85	75	55	25
GS39	Flag leaf	75	45	15	5
GS45	Booting	65	25	7	2
GS49	1st awns	50	10	3	1
GS55	Mid-heading	40	5	2	0
GS65	Mid-flower	12	2	1	0

The complication with APR in Table 1 is that some cultivars such as Gregory<sup>1</sup> (rated as resistant (R) to stripe rust) may display infection at GS30 but have never recorded losses as great as 25% with the current pathotypes. This is because APR switches on, ensuring that the disease does not develop in the resistant cultivar. Indeed, it is unlikely that a cultivar could be rated as resistant if it were subject to yield losses of 25% from an early infection. Hence, although the table is a useful guide to losses at particular growth stages for more susceptible cultivars, it is not useful for resistant cultivars.

Nonetheless, the data illustrate that the earlier the disease infects the crop, irrespective of variety resistance rating, the greater the expected loss.<sup>6</sup>

### *Influence of disease onset on optimum timings of fungicide spray for very susceptible cultivars*

The time of disease onset of stripe rust not only influences the expected return from foliar fungicides, it also influences the timing of fungicide applications in order to achieve the greatest return.

What difference does it make to fungicide strategy if stripe rust infects the crop at GS32 (second node) v. GS39 (flag-leaf emergence on the main stem)?

<sup>5</sup> N Poole (2011) Cereal growth stages and decision making for fungicide timing. GRDC Update Papers, 7 Sept. 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Cereal-growth-stages-and-decision-making-for-fungicide-timing>

<sup>6</sup> N Poole (2011) Cereal growth stages and decision making for fungicide timing. GRDC Update Papers, 7 Sept. 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Cereal-growth-stages-and-decision-making-for-fungicide-timing>

This scenario was presented during research in Young, New South Wales, in 2004 with the very susceptible cultivar H45<sup>1</sup> (GRDC project SFS0006). Stripe rust arrived in the district at the beginning of October. One research trial had been established in early July, another in early June. The early-sown trial was infected at flag-leaf emergence (GS39, Figure 1), whereas the later sown trial was infected at second node (GS32). So, if one unit of fungicide were available, in this case Folicur<sup>®</sup> at 145 mL/ha, what would be the best use?

1. Spray both crops at flag leaf (GS39), this being the most cost-effective timing in most fungicide trials?
2. Split the fungicide between two timings, the first applied at GS32 and the other at GS39?
3. Treat the two crops with a different strategy?



Figure 1: Flag leaf. (Photo: Foundation of Arable Research)

The scenario and results are summarised as follows. For the July-sown crop

- yield potential 5 t/ha
- disease onset GS32 (second node)
- disease onset 1 October
- significant advantage to spraying twice
- 2.51 t/ha response to fungicide (52% loss)

For the June-sown crop

- yield potential 6 t/ha
- disease onset GS39 (flag leaf)
- disease onset 1 October
- no advantage to spraying twice
- 2.01 t/ha response to fungicide (34% loss)

Therefore, where stripe rust infection occurred at second node (GS32), the two-spray program was optimal, but with a later, flag-leaf infection, there was no advantage to applying fungicide twice. It is arguable that because fungicides are insurance inputs, the more consistent program of the two trials (in terms of disease control and yield response) was fungicide applied at both stages: second node (GS32) and flag leaf (GS39).

Would the result be the same if a cultivar had a low level of APR rather than a very susceptible rating for stripe rust?

Cultivar Wyalkatchem<sup>1</sup> is rated susceptible for stripe rust resistance but is acknowledged as having a low level of APR. In order to examine the interaction between cultivar resistance and environment, this cultivar (in 2008 and 2009) and Derrimut<sup>1</sup> (in

2010), with moderately susceptible rating to stripe rust, were sown at two sowing dates in the long-season, southern Victorian, high-rainfall zone at Inverleigh.

The questions to be answered were:

- Would later sowing exhibit greater disease resistance than earlier sowing, acknowledging that later sowings develop later in the season in a climate that is usually warming and therefore less conducive to stripe rust infection and fungicide response? Might it also encourage greater APR if the switches for APR genes were linked to temperature, a feature of APR expression in some cultivars?
- Alternatively, would stripe rust onset be the same for all crops in the district, later sown crops being infected at earlier growth stages and therefore giving greater response to fungicide?

Three years of data (2008–2010) revealed that Wyalkatchem<sup>®</sup> and Derrimut<sup>®</sup> had greater responses to fungicides when sown later (June) as opposed to early sowing (May), despite lower yield potential (Figure 2). During the 3 years, stripe rust infection was observed to arrive in the district. This resulted in the earlier sowings first showing infection at more advanced growth stages (relative to the later sowings), which was then less damaging to yield than experienced with later sowings. By contrast, later sowings first showed infection at a similar calendar date, but at earlier growth stages. The results illustrated that later June sowings of these susceptible cultivars gave greater response to fungicide application, because stripe rust infection occurred at earlier growth stages than for the earlier May sowings.

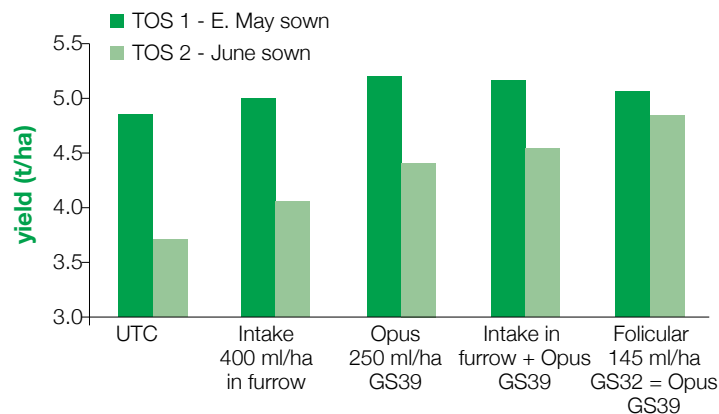
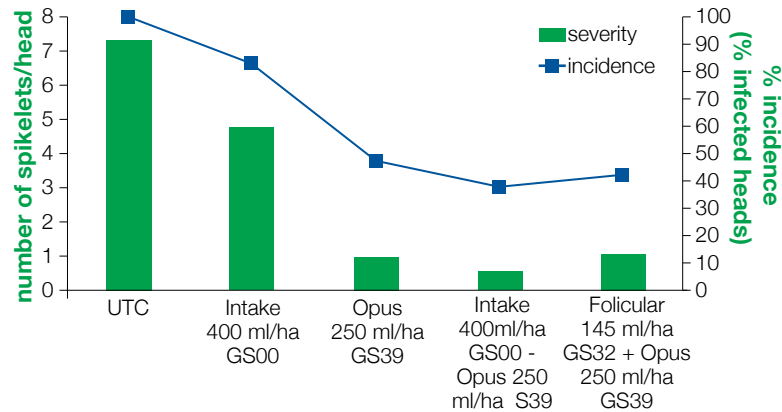


Figure 2: Influence of sowing date on yield response to fungicide application for stripe rust control in Wyalkatchem<sup>®</sup> and Derrimut<sup>®</sup>, for two sowing dates at Inverleigh, southern Victoria, 2008–2010 (3-year yield mean).

The trial also indicated that although none of the fungicide treatments directly applied fungicide to the head, treatments that were effective in reducing stripe rust in the foliage were also effective in reducing head infection (Figure 3). In addition, earlier May sowings suffered later build-up of stripe rust infection and consequently had less head infection.<sup>7</sup>

<sup>7</sup> N Poole (2011) Cereal growth stages and decision making for fungicide timing. GRDC Update Papers, 7 Sept. 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Cereal-growth-stages-and-decision-making-for-fungicide-timing>



**fungicide treatment**  
LSD (5%) severity - spikelets incidence - 35%

Figure 3: Influence of fungicide treatment for control of disease in the foliage and its subsequent effect on infection in the head, June-sown Derrimut<sup>8</sup>, at Inverleigh, southern Victoria, 2010. <sup>8</sup>

To hear Nick Poole discuss canopy management, visit: [GRDC Driving Agronomy – Disease management and crop canopies](#).

For more information on registered plant growth regulators, visit [Australian Pesticides and Veterinary Medicines Authority](#).

<sup>8</sup> N Poole (2011) Cereal growth stages and decision making for fungicide timing. GRDC Update Papers, 7 Sept. 2011, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Cereal-growth-stages-and-decision-making-for-fungicide-timing>



SECTION 11

# Crop desiccation/spray out

Not applicable for this crop.

## SECTION 12

# Harvest

Harvest can commence whenever the header is capable of giving a clean grain sample (Figure 1). This is usually when grain moisture is <20%. Where grain-drying facilities are available, harvesting can start well before the crop dries down to the required 12.5% moisture, reducing the time the crop has to stand at risk from weather damage in the field.

Grain density standard is 75 kg/hectolitre (hL), although wheat often achieves 80 kg/hL.<sup>1</sup>

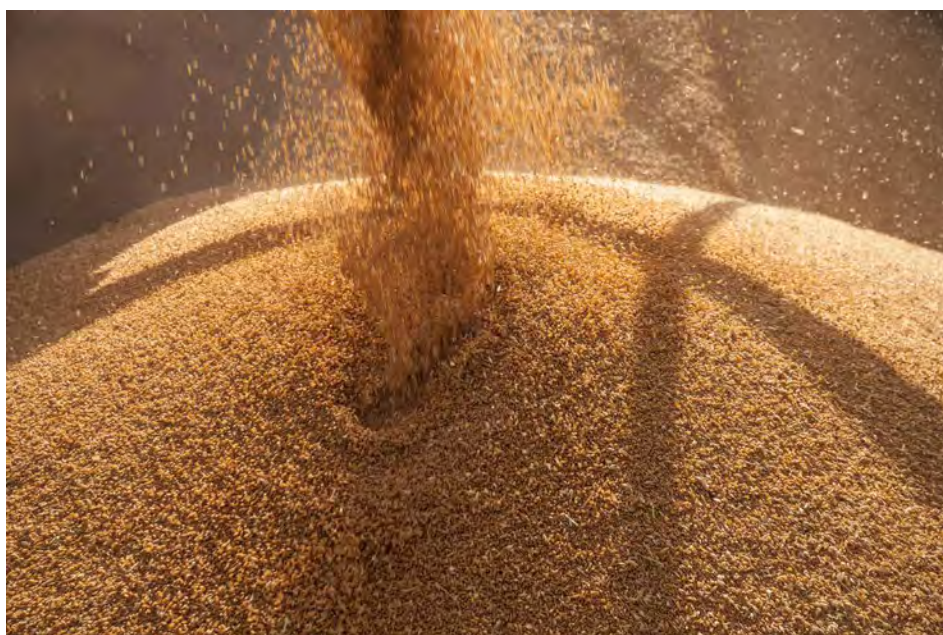


Figure 1: Harvest under way.

## More information

GRDC Fact Sheets:  
[Pre-harvest herbicide \(Northern, Western and Southern Regions\)](#)

### 12.1 Pre-harvest spraying with glyphosate

Timing of glyphosate application is important; certain glyphosates are registered for pre-harvest spraying, and several other groups for salvage control. For more information, visit: [Public Chemical Registration Information System Search](#).

### 12.2 Wet harvest issues and management

Ideally, harvest begins as soon as the crop is mature or ripe. A cereal crop can be harvested any time after it reaches physiological maturity and dries down from about 20% moisture content (MC). In most situations, however, harvest does not begin as soon as the crop is ready. The actual start of harvest is usually dictated by the options each grain grower has available to deal with high moisture grain. For example, a grower with access to a heated air dryer could harvest at 18% MC and a grower with

<sup>1</sup> DAF Qld (2012) Harvesting and yield. Department of Agriculture and Fisheries, <http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/harvesting-information>

aerated storage could harvest at ~15% MC, whereas a grower without high-moisture management techniques would have to wait until the moisture was <12.5%.<sup>2</sup>

### 12.2.1 Delaying harvest

Every day a harvestable crop stands in the paddock, it is exposed to ongoing yield loss and quality degradation (Figure 2). Yield is reduced by shedding, head loss and general exposure to the elements. This is measured as a loss of yield each day in dry matter (DM). Research on this topic in the 1980s at Esperance by M Bolland and J Richardson (from the then Western Australian Department of Agriculture) revealed daily DM losses for wheat of 0.18–0.53% and for barley of 0.25–0.75% (depending on the season and distance from the ocean).

Most growers have also experienced some form of grain quality loss due to delayed harvest and associated rain. Fungal growth reduces the end use possibilities.

These factors can combine to result in heavy discounts from a crop's net return. Time increases these risks, and ongoing exposure to moisture will eventually cause yield loss and development of one or more of these quality defects.

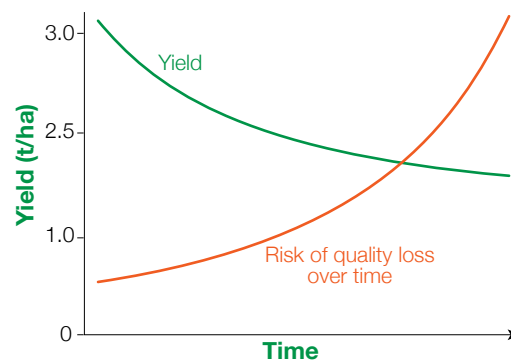


Figure 2: Yield loss and risk of quality loss over time

### 12.2.2 Weed management

Extreme wet weather during harvest across areas of the Australian winter cropping zone can present large problems with weed management for grain growers. Wet conditions can promote growth of weeds in the standing crop that may have been present prior to the rain, with many summer weeds germinating as soil temperatures increase. Growers will want to harvest the crops as quickly as possible to maintain grain quality. Herbicide residues are a real risk, and it is critical that only registered herbicides or those with a 'permit' are used prior to harvest and that harvest-withholding periods are strictly observed. These problems are greatly compounded if weeds resistant to glyphosate or paraquat are present.<sup>3</sup>

### 12.2.3 Seed retention

Saving viable grain seed following a wet harvest requires careful collection, storage, handling and subsequent planting. Retained seed must be graded and tested for germination and vigour.

All crops are susceptible to deterioration in seed quality during wet harvests. Symptoms can range from mild (a loose and wrinkled seed coat), to severe (seed staining and fully germinated seed). It is essential to recognise whether the damage is cosmetic or the symptom of seed-borne disease, and if it will affect germination.

<sup>2</sup> N Metz (2006) The WA guide to high moisture harvest management, grain storage and handling. CBH Group and South East Premium Wheat Growers Association, Perth, W. Aust, [http://www.giwa.org.au/literature\\_133719/SEPWA\\_and\\_CBH\\_Group\\_-\\_the\\_WA\\_Guide\\_to\\_high\\_moisture\\_harvest\\_management\\_grain\\_storage\\_and\\_handling](http://www.giwa.org.au/literature_133719/SEPWA_and_CBH_Group_-_the_WA_Guide_to_high_moisture_harvest_management_grain_storage_and_handling)

<sup>3</sup> Australian Glyphosate Sustainability Working Group (2011) Wet harvest poses difficult weed management decisions for grain growers. Australian Glyphosate Sustainability Working Group, [http://glyphosateresistance.org.au/media%20releases/mr\\_111221\\_harvest\\_weed\\_management.pdf](http://glyphosateresistance.org.au/media%20releases/mr_111221_harvest_weed_management.pdf)

Seed quality can also decline during storage, and growers are advised to test germination capacity before and during storage, and before planting. Generally, a germination percentage of 80% at planting is considered acceptable, but when testing at harvest, the germination percentage should be higher. Weather-damaged grain is likely to have a lower germination percentage and poorer vigour, so seeding rates should be adjusted accordingly.

With many weedy cereal crops in a wet season, desiccation or crop-topping is often necessary. Depending on timing and chemicals used, this could affect seed quality for sowing.

Growers are reminded that grain must not be retained for seed when glyphosate has been used in pre-harvest applications.

A laboratory seed test should be used to establish the germination percentage of on-farm, retained seed before sowing, especially if it has been damaged by weather. A vigour test is also recommended. Purchased seed will be certified and it should include details of germination percentage.

Key points:

- Ideally retain seed from grain harvested before rain.
- Weather-damaged grain is more susceptible to poor germination, low vigour and degradation during storage and handling, so extra care is needed.
- Harvest under conditions of low moisture and cool temperature. Storage temperature and moisture must be monitored and controlled.
- Germination percentage should be checked at harvest, during storage and before seeding. Low-germination seed should not be used.
- Correct seeding depth, conditions and agronomy are essential when sowing weather-damaged seed.

## 12.3 Fire prevention

Grain growers must take precautions during the harvest season. Operating of machinery in extreme fire conditions is dangerous, and all possible measures must be taken 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 combined with combustible material. This is exacerbated on hot, dry, windy days. Seasonal conditions can also contribute to lower moisture content in grain and therefore a greater risk of fires.<sup>4</sup>

### 12.3.1 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 overheating of tractors, motorcycles, off-road vehicles and other mechanical equipment, all machinery needs to be properly serviced and maintained. Fire-fighting equipment must be available and maintained—it is not just common sense, it is a legal requirement.

Take great care when using this equipment:

- Be extremely careful when using cutters and welders to repair plant equipment; this includes angle grinders, welders and cutting equipment.
- Ensure that machinery components, including brakes and bearings, do not overheat; these components can drop hot metal onto the ground, starting a fire.
- Use machinery correctly—incorrect usage can cause it to overheat and ignite.
- Be aware that when blades of slashers, mowers and similar equipment hit rocks or metal, they can cause sparks to ignite dry grass.

<sup>4</sup> NSW Rural fire Service. Farm fire safety. [NSW Government, http://www.rfs.nsw.gov.au/dsp\\_content.cfm?cat\\_id=1161](http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161)



- Avoid using machinery during inappropriate weather conditions of high temperatures, low humidity and high wind.
- Do repairs and maintenance in a hazard-free, clean working area such as on bare ground, concrete or in a workshop, rather than in the field.
- Keep machinery clean and as free from fine debris as possible to reduce on-board ignitions.<sup>5</sup>

### 12.3.2 Steps to preventing header fires

With research showing that, on average, 12 harvesters are burnt to the ground every year in Australia, agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses (Figure 3).

Key points:

- Most harvester fires start in the engine or engine bay.
- Other fires are caused by failed bearings, brakes and electricals, and rock strikes.
- Regular removal of flammable material from the engine bay is urged.<sup>6</sup>

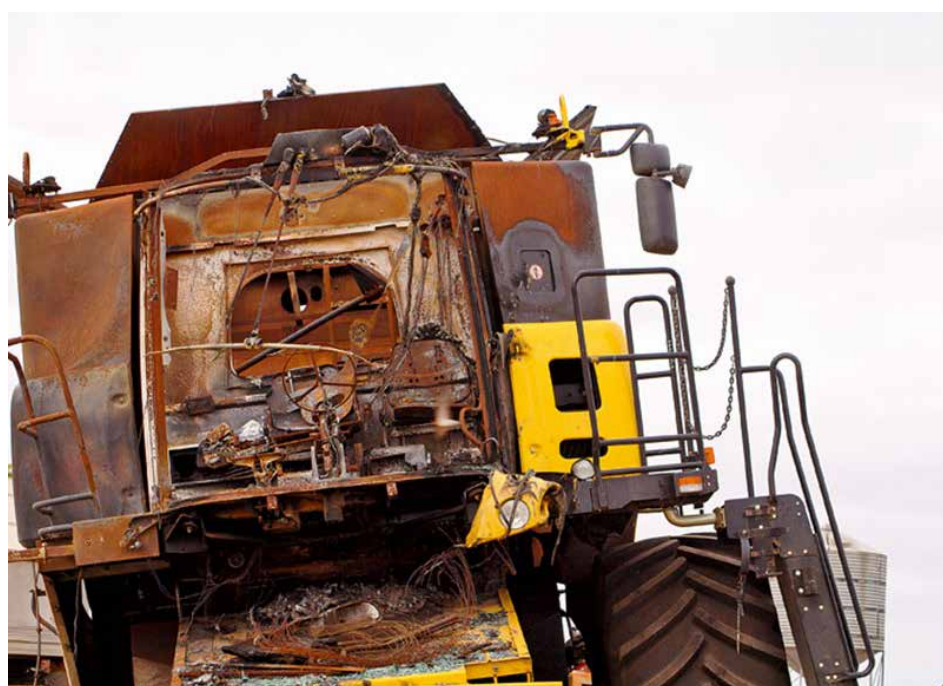


Figure 3: Keeping headers clean can reduce the risk of fire. (Photo: Rebecca Thyer)

#### More information

GRDC Media Centre:  
[Harvester fires](#)

## 12.4 Receival standards

Wheat delivered into the market place must meet certain grain-quality specifications to be classified into the relevant grades. These testing procedures are important benchmarks for end users in determining flour yield and quality for different bread, bakery, pasta and noodle products.

The following grain tests are applied at receival points to measure quality and to ensure that the high standards of Australian wheat grade classification are maintained.

<sup>5</sup> NSW Rural fire Service. Farm fire safety. NSW Government, [http://www.rfs.nsw.gov.au/dsp\\_content.cfm?cat\\_id=1161](http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161)

<sup>6</sup> N Baxter (2012) A few steps to preventing header fires. GRDC Ground Cover Issue 101, <http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-101/A-few-steps-to-preventing-header-fires>

### 12.4.1 Protein content

Protein content is one of the important factors influencing the end uses and markets of wheat; consequently, wheat is graded according to protein content. Protein content is assessed by using near-infrared (NIR) technology on delivery at the silo, and payment is based on protein content. Wheat with 11–13% protein is used for pan bread, 10.5% for udon noodles and 8.5–9.5% for biscuits and cakes.

### 12.4.2 Protein quality

Protein (gluten) quality differs between wheat varieties and so influences the selection of wheat varieties for production applications. For example, bread makers may require a wheat type with strong protein, whereas a manufacturer of steam buns may seek moderate protein strength. For millers, this is an extremely important quality characteristic because it affects flour water absorption and dough mixing characteristics. Protein quality is accounted for at the receival point by variety declaration.

### 12.4.3 Falling number

The falling number test indicates rain damage at harvest. Rain causes mature wheat grains to sprout and activates the alpha-amylase enzyme, which breaks the starchy endosperm into sugars. In this test, wheat is ground, mixed with water and heated to form a gelatinous suspension. The time taken for a plunger to fall through the suspension is measured. Wheat that has been weather-damaged forms a more viscous suspension and so has a lower falling number. End products are sensitive to flour with low falling number, because it can result in dough stickiness, excessively dark bread, or poor crumb texture and poor slicing ability.

### 12.4.4 Screenings

Impurities such as white heads, chaff, weed seeds, and shrivelled and broken grains may need to be removed before milling. Payment is based on screening levels, as extensive grading adversely affects mill profit. Although some grain varieties are more susceptible to high levels of screenings, the environment in which the wheat is grown is a major contributor.

### 12.4.5 Stained grains

Enzymic discoloration such as black point and staining caused by fungal infections (e.g. by *Fusarium*, *Eppicoccum* or *Drechslera* spp.) adversely affect grain quality. In particular, black specks detract from the appearance of noodles.

### 12.4.6 Hardness

Wheat can be physically hard or soft. Hardness affects milling properties. Hard wheats are used to make pan breads, yellow alkaline noodles and flat breads. Soft wheats are used for biscuits and cakes. Soft wheat flour is much finer than hard wheat flour. Variety declaration is used to segregate hard from soft wheat at receival.

### 12.4.7 Moisture content

When wheat is delivered into a silo, moisture content is assessed at receival by NIR technology and payment is based on moisture content. Water content affects the value of grain (water v. flour) and affects the maintenance of quality during handling and storage.

### 12.4.8 Test weight

Test weight is also known as 'hectolitre weight' and assessed by weighing a fixed volume of grain. Hectolitre weight informs the miller of the wheat's cleanness, plumpness and packing density, and guides the miller in predicting flour yield. Test weight differs between varieties, owing to their differences in size and shape. Shrivelled and rain-damaged grains reduce test weight.

View the latest grain-receival standards at GrainCorp Ltd Receival Standards: <http://www.graincorp.com.au/storage-and-logistics/technical-services/technical-documents-and-information>.

The information is in accordance with the Grain Trade Australia (GTA) national grain receival standards.<sup>7</sup>

The GTA Trading Standards are a critical tool for anyone purchasing, selling, trading, broking or operating in the commercial grain industry. The GTA Trading Standards cover all grains, oilseeds, pulses and other related commodities.

## 12.5 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. Thus, if annual weeds are allowed to produce seed that enters the seedbank, the cropping system will inevitably be unsustainable.

Fortunately, seedbank decline is rapid for these weed species, with annual seed losses of 60–80%. Without inputs, a very large seedbank (>1000 seed/m<sup>2</sup>) can therefore be reduced to a very modest one (<100 seed/m<sup>2</sup>) in just 4 years. A small seedbank of weeds allows easier and more effective weed control with 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.<sup>8</sup>

### More information

[GRDC Weed Webinars: Beginners guide to harvest weed seed control](#)

### 12.5.1 Intercepting annual weed seed

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 are now also being rapidly 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 retention are maintained over much of the harvest period (Figure 4). Therefore, the collection and management of the weed-seed-bearing chaff fraction can result in significant reductions in population densities of annual weeds.

Table 1: Proportion of total seed production retained above a low harvest cutting height (15 cm)

Species	Seed retention above 15 cm (%)
Annual ryegrass	88
Wild radish	99
Brome grass	73
Wild oats	85

<sup>7</sup> DPIF Qld (2009) Wheat quality and markets in Queensland. Department of Agriculture and Fisheries, Queensland, [http://www.daff.qld.gov.au/\\_data/assets/pdf\\_file/0006/53799/Wheat-FactSheet-Quality-Markets-Qld.pdf](http://www.daff.qld.gov.au/_data/assets/pdf_file/0006/53799/Wheat-FactSheet-Quality-Markets-Qld.pdf)

<sup>8</sup> 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>

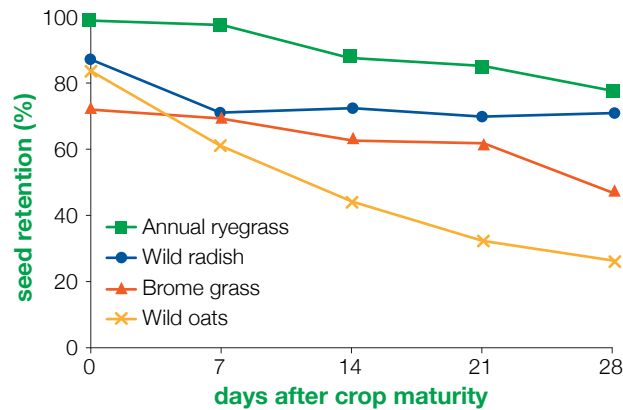


Figure 4: Seed retention above a harvest height of 15 cm over the first 4 weeks of harvest for the major weeds of Western Australian wheat crops.

Lower in-crop weed densities are easier to manage, and their potential development as herbicide-resistant populations is dramatically reduced. Western Australian farmers 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.<sup>9</sup>

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).

## More information

[IWM Section 4: Tactics](#)

### 12.5.2 Burning of narrow windrows

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 is achieved by attaching chutes to the rear of the harvester to concentrate the straw and chaff residues as they exit the harvester (Figures 5 and 6). This concentration of residue increases the seed-destruction potential of residue burning. With more fuel in these narrow windrows, the residues burn hotter than standing stubbles or even conventional windrows. Weed-seed kill levels of 99% for both annual ryegrass and wild radish have been recorded from the burning of wheat, canola and lupin stubble windrows.<sup>10</sup>

<sup>9</sup> 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>

<sup>10</sup> 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>

## More information

[GRDC: Narrow windrow burning in southern New South Wales](#)

[GRDC Report: Developments in stubble retention](#)

[IWM Section 4: Tactics](#)



Figure 5: Harvest in action—producing narrow chaff rows for burning in the following autumn. (Photo: A. Storrie)

## GRDC Videos

[Weed seed bank destruction—windrow chute design](#)

[Weed seed bank destruction—Header setup and tips for narrow windrowing](#)

[Weed seed bank destruction—narrow windrow burning](#)

[Weed seed bank destruction—burning windrows safely](#)

[Weed seed bank destruction—nutrient losses: comparing chaff heaps with narrow windrows](#)

[Weed seed bank destruction—vary windrow placement to avoid potassium concentration](#)



Figure 6: Windrow burning. (Photo: Penny Heuston)

## **i** More information

[IWM Section 4: Tactics](#)

## **▶** GRDC Videos

[Weed seed bank destruction—an integrated approach to weed management](#)

[Weed seed bank destruction—more efficient use of chaff carts](#)

[Weed seed bank destruction—wild radish seed](#)

[Weed seed bank destruction—burning chaff dumps](#)

[Weed seed bank destruction—seeing results from integrated weed management](#)

## **i** More information

[IWM Section 4: Tactics](#)

### 12.5.3 Chaff carts



Figure 7: Chaff cart in action at Tarin Rock, WA. (Photo: A. Storrie)

Chaff carts are towed behind headers during harvest to collect the chaff fraction as it exits the harvester (Figure 7).

The weed-seed collection efficiency of several commercially operating harvesters with attached chaff carts was evaluated by the Australian Herbicide Resistance Initiative (AHRI). Harvesters were found to collect 75–85% of annual ryegrass seeds and 85–95% of wild radish seeds entering the front of the header during the harvest operation. Collected chaff must be managed to remove weed seeds from the cropping system. Typically, this material is left in piles in the paddock to be burnt in the following autumn. In some instances though, chaff is removed from the paddock and used as a source of feed for livestock.<sup>11</sup>

### 12.5.4 Bale-direct systems

An alternative to the *in-situ* burning or grazing of chaff, the bale-direct system uses a 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.<sup>12</sup>

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.<sup>13</sup>

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.<sup>14</sup>

For the story of development of header-towed baling systems, see: <http://www.glenvar.com/>.

<sup>11</sup> 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>

<sup>12</sup> GRDC. Section 6: Managing weeds at harvest. GRDC Integrated Weed Management Hub, <http://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest>

<sup>13</sup> M Walsh, S Powles (2007) Management strategies for herbicide-resistant weed populations in Australian dryland crop production systems. Weed Technology 21, 332–338, [http://www.jstor.org/stable/4495856?seq=1#page\\_scan\\_tab\\_contents](http://www.jstor.org/stable/4495856?seq=1#page_scan_tab_contents)

<sup>14</sup> 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>

## GRDC Videos

[IWM—Harrington Seed Destructor \(3 videos\)](#)

[Weed seed destruction—beer can height](#)

[Weed seed bank destruction—lessons learned—windrowing canola](#)

[Weed seed bank destruction—Spear grass \(\*Bromus spp.\*\) an emerging problem](#)

## More information

[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](#)

### 12.5.5 Chaff grinding—the Harrington Seed Destructor

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. Because of the importance and potential industry benefits of this process, there has been substantial interest in the development of an effective system.

Ray Harrington, a progressive farmer from Darkan, Western Australia, invented and developed the Harrington Seed Destructor (HSD), a cage-mill-based system attached to the back of the harvester that processes chaff during harvest.

The HSD system comprises a chaff-processing cage mill, and chaff and straw delivery systems. The retention of all harvest residues in the field reduces the loss and/or banding of nutrients and maintains all organic matter to protect the soil from wind and water erosion, as well as reducing evaporation loss compared with windrow burning, chaff carts and baling.<sup>15</sup>

Evaluation under commercial harvest conditions by AHRI has determined that the HSD will destroy  $\geq 95\%$  of annual weed seed during harvest. With the efficacy of the HSD system well established, its development has progressed to commercial production.<sup>16,17</sup>

## 12.6 Summary

Productive, large-scale conservation cropping as practiced 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.<sup>18</sup>

<sup>15</sup> GRDC. Section 6: Managing weeds at harvest. GRDC Integrated Weed Management Hub, <http://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest>

<sup>16</sup> 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>

<sup>17</sup> de Bruin Engineering. Harrington Seed Destructor. Projects, De Bruin Engineering, <http://www.debruinengineering.com.au/projects/harrington-seed-destroyer/>

<sup>18</sup> 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>

## GRDC Update papers

[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 east](#)

## 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 dumps](#)

[WeedSmart: Narrow windrow burn like a pro](#)

[WeedSmart: Setting up your header for 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 wheat (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: QDAFF)

Grain Trade Australia (GTA) stipulates standards for heat-damaged, bin-burnt, storage-mould-affected or rotten wheat, all of which can result in the discounting or rejection of grain. GTA has nil tolerance to live, stored-grain insects for all grades of wheat from premium milling grades to feed.<sup>1</sup> Effective management of stored grain can eliminate all of these risks to wheat quality.

In grain storages in target grain temperatures of stored wheat should be 20–23°C during summer and <15°C in winter.<sup>2</sup>

### **i** More information

[GRDC Ground Cover: Biosensors to detect trouble early](#)

[GRDC Stored Grain Information Hub](#)

[GRDC: Northern & southern regions grain storage pest control guide](#)

[GRDC: Northern & southern regions stored grain pests – identification](#)

[GRDC Ground Cover: Grain storage](#)

<sup>1</sup> GTA (2013) Wheat Standards, 2013/2014 season. Grain Trade Australia, August 2013, [http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/2013\\_2014/Section%2002%20-%20Wheat%20Standards%20201314%281%29.pdf](http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/2013_2014/Section%2002%20-%20Wheat%20Standards%20201314%281%29.pdf)

<sup>2</sup> P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014. GRDC Update Papers, 18 July 2013, <https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014>

## 13.1 How to store wheat on-farm

According to the Kondinin Group National Agricultural Survey 2011, silos account for 79% of Australia's on-farm grain storage, compared with 12% for bunkers and pits and 9% for grain bags.

Aerated silos that can be sealed during fumigation are widely acknowledged as the most effective way to store wheat on-farm (Table 1). There is now an Australian standard (AS2628) for sealable silos that manufacturers in Australia can choose to use as a construction standard to ensure reliable fumigation results.

Watch this GRDC Ground Cover TV clip to find out more.



Table 1: Advantages and disadvantages of grain storage options

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	<ul style="list-style-type: none"> <li>Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects</li> <li>Easily aerated with fans</li> <li>Fabricated on-site or off-site and transported</li> <li>Capacity from 15 to 3000 t</li> <li>Service life up to 25 years or more</li> <li>Simple in-loading and out-loading</li> <li>Easily administered hygiene (cone base particularly)</li> <li>Can be used multiple times in-season</li> </ul>	<ul style="list-style-type: none"> <li>Requires foundation to be constructed</li> <li>Relatively high initial investment required</li> <li>Seals must be regularly maintained</li> <li>Access requires safety equipment and infrastructure</li> <li>Requires an annual test to check gas-tight sealing</li> </ul>
Non-sealed silo	<ul style="list-style-type: none"> <li>Easily aerated with fans</li> <li>7–10% cheaper than sealed silos</li> <li>Capacity from 15 to 3000 t</li> <li>Service life up to 25 years or more</li> <li>Can be used multiple times in-season</li> </ul>	<ul style="list-style-type: none"> <li>Requires foundation to be constructed</li> <li>Silo cannot be used for fumigation—see phosphine label</li> <li>Insect-control options limited to protectants in eastern states and Dryacide® in Western Australia</li> <li>Access requires safety equipment and infrastructure</li> </ul>

Storage type	Advantages	Disadvantages
Grain storage bags	<ul style="list-style-type: none"> <li>• Low initial cost</li> <li>• Can be laid on a prepared pad in the paddock</li> <li>• Provide harvest logistics support</li> <li>• Can provide segregation options</li> <li>• Are all ground-operated</li> <li>• Can accommodate high-yielding seasons</li> </ul>	<ul style="list-style-type: none"> <li>• Requires purchase or lease of loader and unloader</li> <li>• Increased risk of damage beyond short-term storage (typically 3 months)</li> <li>• Limited insect-control options, fumigation only possible under specific protocols</li> <li>• Requires regular inspection and maintenance, which needs to be budgeted for</li> <li>• Aeration of grain in bags currently limited to research trials only</li> <li>• Must be fenced off</li> <li>• Prone to attack by mice, birds, foxes, etc.</li> <li>• Limited wet-weather access if stored in paddock</li> <li>• Need to dispose of bag after use</li> <li>• Single-use only</li> </ul>
Grain storage sheds	<ul style="list-style-type: none"> <li>• Can be used for dual purposes</li> <li>• Service life 30 years or more</li> <li>• Low cost per stored tonne</li> </ul>	<ul style="list-style-type: none"> <li>• Aeration systems require specific design</li> <li>• Risk of contamination from dual-purpose use</li> <li>• Difficult to seal for fumigation</li> <li>• Vermin control is difficult</li> <li>• Limited insect-control options without sealing</li> <li>• Difficult to unload</li> </ul>

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.<sup>3</sup>

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 stages of the life cycle. 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 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.<sup>4</sup>

<sup>3</sup> 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-controlled-atmospheres.pdf?shortcut=1>

<sup>4</sup> P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. Grain Storage Fact Sheet, GRDC, September 2010, <https://www.grdc.com.au/~media/0218DA4A22264A31B6202718043758DE.pdf>

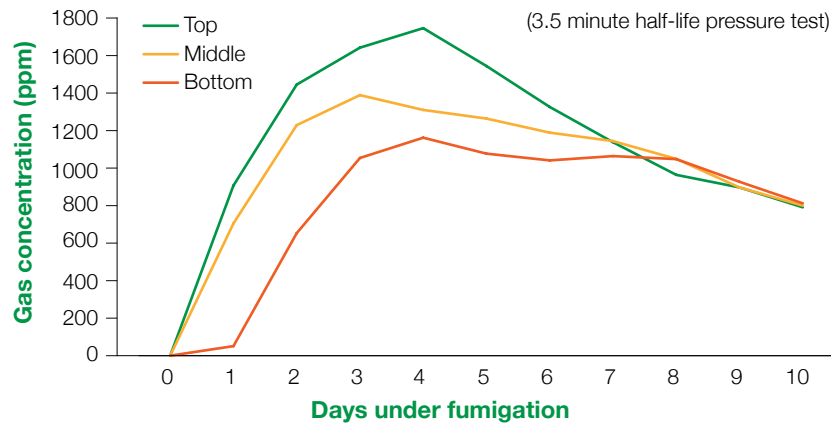


Figure 2: Gas concentration in gas-tight silo. (Source: QDAFF)

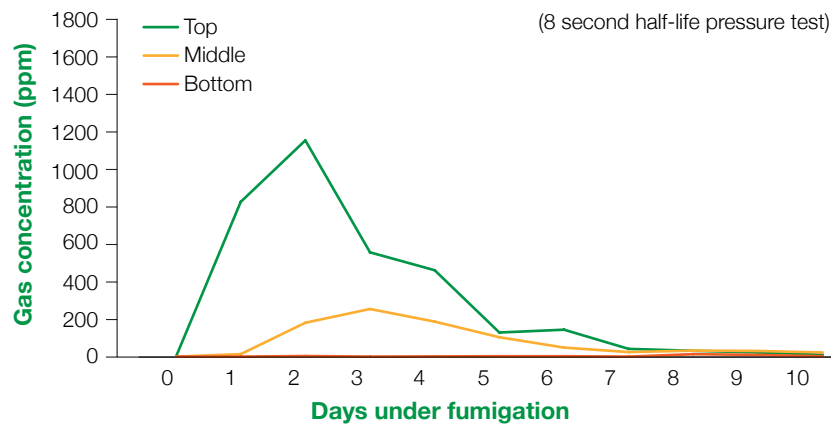


Figure 3: Gas concentration in a non-gas-tight silo. (Source: QDAFF)

To find out more about how to pressure-test silos, visit: [Fumigating with phosphine, other fumigants and controlled atmospheres.](#)

Aeration of stored wheat 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 potentially cause grain damage. Most aeration controllers have hour meters fitted, so run-times can be checked to ensure they are within range of the expected total average hours per month, for example, 100 h/month.

It is important to separate aeration systems commonly used for 'aeration cooling' and aeration systems 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 while 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. Losses of grain quality 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 itself.<sup>5</sup>

<sup>5</sup> P Burrill, A Ridley, C Saunders, A Andrews, A Kotzur (2012) Performance testing aeration systems. Grain Storage Fact Sheet, GRDC, August 2012, <http://www.grdc.com.au/Resources/Factsheets/2012/08/Grain-Storage-Performance-testing-aeration-systems>

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 silo of capacity 150 t) 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.

Several 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](#).

A GRDC Fact Sheet explaining how to build and use an A-Flow is available at: [Performance testing aeration systems](#).

### More information

[GRDC: 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 (Figure 4). 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 a single 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 breed best in warm conditions. Insects will also breed in outside dumps of unwanted grain. 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 to other insect predators.



Figure 4: Poor grain hygiene undermines effective stored grain insect control. (Photo: QDAFF)

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 was considered reasonably clean at the end of the previous season.<sup>6</sup>

Further studies in Queensland revealed that insects are least mobile during the colder winter months of the year. Cleaning around silos during winter can reduce insect numbers before they become mobile.



Figure 5: Lesser grain borer, *Rhyzopertha dominica*. (Photo: QDAFF)

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 of 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 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 now require 'pesticide residue free' (PRF) grain; therefore, growers are advised to check with potential grain buyers before using grain protectants or structural treatments.

To find out more about what to use and when, and how to clean equipment and storages to minimise the chance of insect infestation, download the GRDC Grain Storage Fact Sheet [Hygiene and structural treatment for grain storages](#).

<sup>6</sup> P Burrill, P Botta, C Newman, B White, C Warrick (2013) Northern and southern regions—grain storage pest control guide. Grain Storage Fact Sheet, GRDC, June 2013, <http://www.grdc.com.au/Resources/Factsheets/2013/06/Grain-Storage-Fact-Sheet-Grain-Storage-Pest-Control-Guide>

### 13.3 Grain protectants and fumigants

Grain Trade Australia is aware of cases where chemicals that are not approved for grain or a particular grain type have been used to treat stored grain. When such cases are detected, an entire shipload can be rejected, often with serious long-term consequences for important Australian grain markets.

Market requirement for 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. 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 problems. The grain industry has adopted a voluntary strategy to manage the build-up of phosphine resistance in pests. Its core recommendations are to limit 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.<sup>7</sup>



Figure 6: Phosphine is widely accepted as having no residue issues. (Photo: QDAFF)

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

<sup>7</sup> 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](http://www.graintrade.org.au/sites/default/files/file/Phosphine_Strategy.pdf)

helping to prolong phosphine’s effective life, as well as increasing the usefulness of the break strategy.<sup>8</sup>

Chemical options for treatment of stored grain, and efficacy against various stored grain insects, are presented in Table 2.

Table 2: Stored grain chemical treatments: resistance and efficacy guide for stored grain insects (northern and southern regions) in cereal grains

Treatments	WHP (days)	Lesser grain borer ( <i>Rhyzopertha dominica</i> )	Rust-red flour beetle ( <i>Tribolium castaneum</i> )	Rice weevil ( <i>Sitophilus oryzae</i> )	Saw-toothed grain beetle ( <i>Oryzaephilus surinamensis</i> )	Flat grain beetle ( <i>Cryptolestes ferrugineus</i> )	Psocids (booklice) (Order Psocoptera)	Structural treatments
Grain disinfectants - used on infested grain to control full life cycle (adults, eggs, larvae, pupae).								
Phosphine (eg Fumitoxin <sup>®</sup> ) <sup>A,C</sup> when used in gas-tight, sealable stores	2	Effective control	Effective control	Effective control	Effective control	High-level resistance in flat grain beetle has been identified, send insects for testing if fumigation failures occur	Effective control	
Sulfuryl fluoride (eg ProFume <sup>®</sup> ) <sup>J</sup>	1	Effective control	Effective control	Effective control	Effective control	Effective control	Effective control	
Dichlorvos (eg Dichlorvos 1140 <sup>®</sup> ) <sup>K</sup>	7-28	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Effective control	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment
Grain protectants – applied post harvest. Poor adult control if applied to infested grain.								
Pirimiphos-methyl (eg Actellic 900 <sup>®</sup> )	nil <sub>2</sub>	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment
Fenitrothion (eg Fenitrothion 1000 <sup>®</sup> ) <sup>D</sup>	1-90	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Effective control	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment
Chlorpyrifos-methyl (eg reldan Grain Protector <sup>®</sup> ) <sup>E</sup>	nil <sub>B</sub>	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment
Methoprene (Grain Star 50 <sup>®</sup> )	nil <sup>F</sup>	Effective control	Effective control	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment
‘Combined products’ (eg Reldan Plus IGR Grain Protector)	nil <sub>B</sub>	Resistance widespread (unlikely to be effective)	Effective control	Effective control	Effective control	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment
Deltamethrin (eg K-Obiol <sup>®</sup> ) <sup>J</sup>	nil <sub>B</sub>	Effective control	Effective control	Effective control	Effective control	Effective control	Effective control	
Diatomaceous earth, amorphous silica – effective internal structural treatment for storages and equipment. Specific use grain treatments.								
Diatomaceous earth, amorphous silica (eg Dryacide <sup>®</sup> ) <sup>H</sup>	nil <sub>B</sub>	Effective control	Effective control	Effective control	Effective control	Effective control	Effective control	Resistant species likely to survive this structural treatment for storage and equipment

WHP Withholding Period; DE, diatomaceous earth.

- Not registered for this pest
- High-level resistance in flat grain beetle has been identified, send insects for testing if fumigation failures occur
- Resistant species likely to survive this structural treatment for storage and equipment
- Resistance widespread (unlikely to be effective)
- Effective control

<sup>A</sup> unlikely to be effective in unsealed sites, causing resistance, see label for definitions  
<sup>B</sup> When used as directed on label  
<sup>C</sup> Total of (exposure + ventilation + withholding) = 10 to 27 days  
<sup>D</sup> Nufarm label only  
<sup>E</sup> Stored grains except malting barley and rice/ stored lupins registration for Victoria only/ not on stored maize destined for export  
<sup>F</sup> When applied as directed, do not move treated grain for 24 hours  
<sup>G</sup> Periods of 6–9 months storage including mixture in adulticide, eg Fenitrothion at label rate  
<sup>H</sup> Do not use on stored maize destined for export, or on grain delivered to bulk-handling authorities  
<sup>I</sup> Dichlorvos 500g/L registration only  
<sup>J</sup> Restricted to licensed fumigators or approved users  
<sup>K</sup> Restricted to use under permit 14075 only. Unlikely to be practical for use on farm

Source: Registration information courtesy of Pestgenie, APVMA and InfoPest (DEEDI) websites

<sup>8</sup> C Norwood (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>



According to research at Queensland's Department of Agriculture, Fisheries and Forestry (DAFF), 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 disinfectant. Supplied under the trade name ProFume®, SF can be used only by a licensed fumigator.

Field trials have shown that SF can control strongly phosphine-resistant populations of the rusty grain beetle. 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 using SF as an alternative fumigant to phosphine. 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 continues. Complimentary laboratory experiments have shown that phosphine resistance does not show cross-resistance to SF, which is an additional advantage of using SF.<sup>9</sup>

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 efficient and 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 stockfeed. Total time required for fumigating ranges from 7 to 20 days depending on grain temperature and the storage structure.

To find out more, visit: [Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide.](#)

Two new grain protectants are now available:

- K-Obio® (active ingredients deltamethrin 50 g/L, piperonyl butoxide 400 g/L). Features acceptable efficacy against the common storage pest lesser grain borer, which has developed widespread resistance to current insecticides. Insect resistance surveys have consistently detected low levels of deltamethrin-resistant 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.<sup>10</sup>
- 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 disinfectant 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, saw-toothed beetle, flat grain beetles, storage moths and psocids (booklice). However, it does not fully control all stages of rice weevil. Must only be used by a licensed fumigator.

<sup>9</sup> M Nayak (2012) Sulfuryl fluoride—a solution to phosphine resistance? GRDC Grains Research Update Northern Region, Spring 2012, Issue 66, <https://www.grdc.com.au/-/media/DAF5F438D9644D90B9A4FA9716B2014E.pdf>

<sup>10</sup> P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014. GRDC Update, 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>

Controlled atmosphere or non-chemical treatment options include:

- Carbon dioxide (CO<sub>2</sub>). Displaces the oxygen inside a gas-tight silo with a high concentration of CO<sub>2</sub> combined with a low-oxygen atmosphere lethal to grain pests. To achieve complete kill of all grain pests at all life stages, CO<sub>2</sub> must be maintained at a minimum concentration of 35% for 15 days.
- Nitrogen (N<sub>2</sub>). Provides insect control and quality preservation without chemicals. It is safe to use and environmentally acceptable. The main operating cost is electricity used by the equipment to produce nitrogen gas. The process uses pressure swing adsorption technology to produce N<sub>2</sub>, thereby modifying the atmosphere within the grain storage to create a very high concentration of N<sub>2</sub>, and starving insect pests of oxygen.<sup>11</sup> There are no residues, so grains can be traded at any time

Silo bags as well as silos can be fumigated (Figure 7). Research conducted by Andrew Ridley and Philip Burrill from DAFF 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. Fumigation trials on a typical, 75-m-long bag containing ~230 t of grain successfully controlled all life stages of the lesser grain borer.



Figure 7: Silo bags can also be fumigated. (Photo: QDAFF)

When using phosphine in silos or silo bags, phosphine tablets are not to be mixed 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 trials where spears were spaced 12 m apart, the phosphine gas took too long to diffuse throughout the whole bag.<sup>12</sup>

<sup>11</sup> 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-controlled-atmospheres.pdf?shortcut=1>

<sup>12</sup> P Burrill, A Ridley (2012) Silo bag fumigation. GRDC Research Update Northern Region, Spring 2012, Issue 66, <http://www.grdc.com.au/~media/DAF5F438D9644D90B9A4FA9716B2014E.pdf>

**i** More information

[GRDC Research Updates: Silo bag fumigation](#)

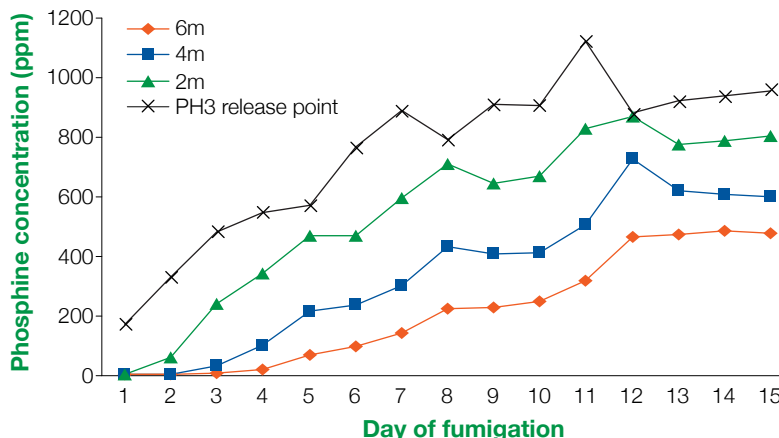


Figure 8: Spread of phosphine gas in a silo bag from a release point to gas-monitoring lines at 2, 4 and 6 m along a silo bag.

### 13.4 Aeration during storage

Aeration has a vital role in both 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 last for 1 or 2 weeks.

Aeration typically reduces stored grain temperatures by >10°C during summer (Figure 9), which significantly reduces the threat of a serious infestation of insects.<sup>13</sup>

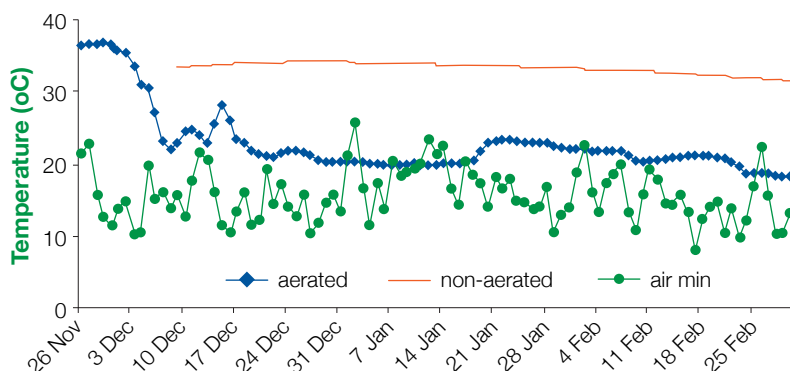


Figure 9: Comparison of wheat grain temperatures in aerated and non-aerated silos.

As soon as grain is harvested and put in storage, run the aeration system non-stop for the first 5 days to reduce grain temperatures and produce uniform moisture conditions in the grain bulk. Without aeration, grain holds its heat, being an effective insulator, and will maintain its warm harvest temperature for a long time (Figure 9). Wheat at typical harvest temperatures of 28–35°C and moisture content >13–14% provides ideal conditions for mould and insect growth (Table 3).<sup>14</sup>

<sup>13</sup> 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>

<sup>14</sup> P 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/Resources/Factsheets/2013/06/Grain-Storage-Dealing-with-highmoisture-grain>

Table 3: 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 still survive at low temperatures, most stages of the life cycle of storage pests are very slow or development is stopped at temperatures below 18–20°C. One of the more cold-tolerant pests, the common rice weevil, does not increase its population at grain temperatures <15°C. The life cycles of insect pests (egg, larvae, pupae and adult) 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 wheat at 12% moisture content stored for 6 months at 30–35°C (unaerated grain temperature) will have reduced germination percentage and seedling vigour.

A national upper limit for moisture of 12.5% applies to wheat at receipt, but deliveries are usually in the range 10.5–11%.<sup>15</sup> Special measures must be taken to minimise the risk of insect infestations or heat damage if the wheat is harvested in damp conditions.

Research by the NSW Department of Primary Industries has shown that grain temperature should be kept below 15°C to protect seed quality and stop all major insect infestations, and aeration slows the rate of deterioration of seed if the moisture content is kept at 12.5–14%.<sup>16</sup>

A trial by DAFF Qld revealed that high-moisture grain generates heat when placed 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).<sup>17</sup>

<sup>15</sup> Wheat Quality Objectives Group (2009) Understanding Australian wheat quality. GRDC, <http://www.grdc.com.au/~media/6F94BAEDAAED4E66B02AC992C70EB776.pdf>

<sup>16</sup> NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/449367/Procrop-wheat-growth-and-development.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf)

<sup>17</sup> P 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/Resources/Factsheets/2013/06/Grain-Storage-Dealing-with-highmoisture-grain>

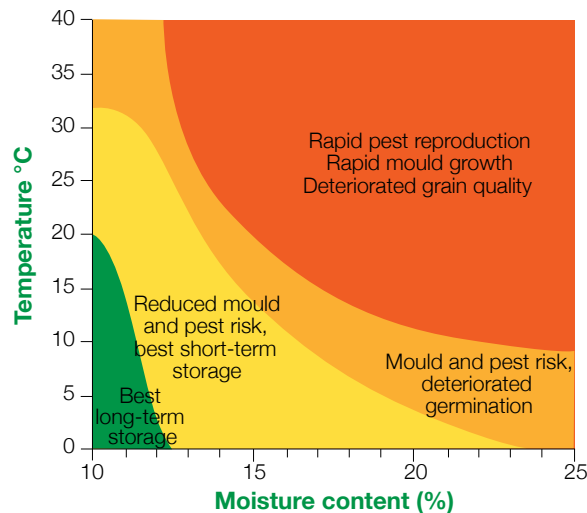


Figure 10: Effects of temperature and moisture on stored grain. (Source: CSIRO Ecosystems Sciences as published in <http://www.grdc.com.au/~lmedia/36D51B725EF44EC892BCD3C0A9F4602C.pdf>)

If the use of a grain dryer is not an option, grain that is over the standard safe storage moisture content of 12% and up to the moderate moisture level of 15% can be managed by aerating until drying equipment is available. Blending with low-moisture grain and aerating is another commonly used strategy (Figure 11).

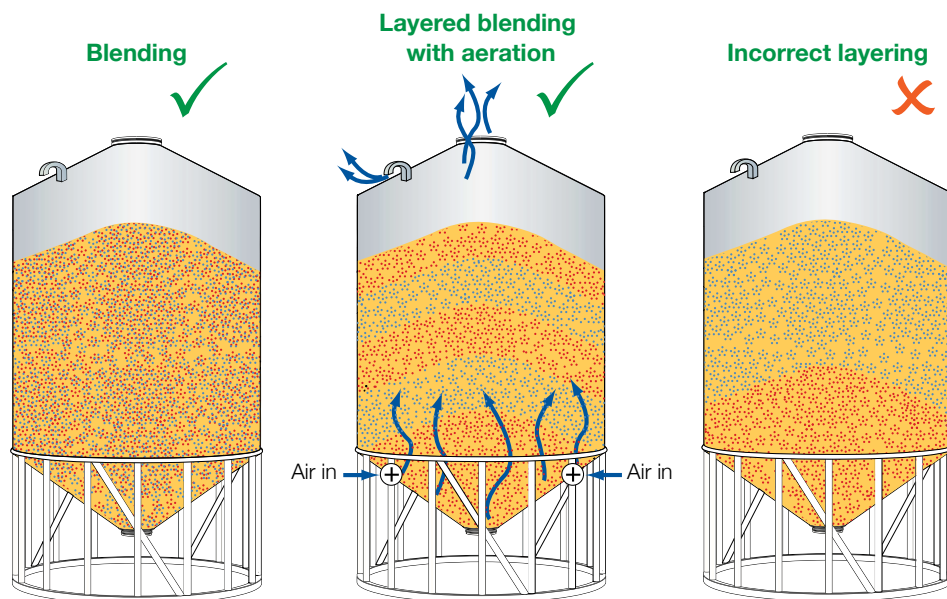


Figure 11: Correct blending with low-moisture grain. (Source: Kondinin Group)

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 wheat in batches or with continuous-flow, before it is put into silos, but excessive heat applied post-harvest can reduce the quality of milling wheat.

A wet harvest or damp conditions can make drying prior to storage a necessity. These rules will help you to decide whether it is safe to store your wheat without drying:

## **i** More information

[GRDC Fact Sheet: Dealing with high-moisture grain](#)

- Wheat that does not exceed the maximum moisture level of 12.5% can be aeration-cooled without drying to slow insect development and maintain quality during storage.
- Grain of <15% moisture can be safely held under continuous aeration for a number of weeks until a hot-air drier or an aeration-drying process can take place to reduce the moisture for safe, longer term storage. Blending with dry grain and aerating may also be feasible.
- Grain of >15% moisture should be dried to a safe storage moisture immediately, and then held under normal aeration cooling for maintenance.

## 13.5 Monitoring wheat

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 environment must be identified so that growers can exploit the best use of chemical and/or non-chemical control measures.

Wheat 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 of seed, with serious consequences for the next wheat 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 need to be recorded (Figure 12).<sup>18</sup>



Figure 12: Keep records of findings from monitoring of stored grain insects. (Photo: QDAFF)

The lesser grain borer and rust-red flour beetle are two of the most common insect pests found in stored cereals. Other common species include weevils, the saw-toothed grain beetle, flat grain beetles and rusty grain beetle, psocids (booklice), Indian meal

<sup>18</sup> 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>

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 also 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 month (4 weeks) for early pest detection. Pitfall traps installed in the top of the grain store will also aid 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, again, to make small insects easier to see. Sieves should have 2-mm mesh and need to hold at least 1 L of grain.
- To help identify live grain pests, place them into a clean glass container. Briefly warm the jar in the sun to encourage insect activity. Weevils and saw-toothed 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 saw-toothed grain beetles do not.<sup>19</sup>

Research in Queensland has shown that the grain industry may need to consider an area-wide approach to pest and resistance management. The research indicates flight dispersal by the lesser grain borer and the rust-red flour beetle, both of which are major insect pests of stored grain. Beetle traps were set along a 30-km transect in the Emerald district and showed that the lesser grain borer flies all year round in Central Queensland, whereas the flour beetle appeared to be located mainly around storages during the winter months, spreading into the surrounding district in summer. This study highlights the importance of finding and dealing with infestations to limit the number of pests that can infest clean grain. In another study, beetles were found to be flying between farms on a scale of at least 100 km.<sup>20</sup>

NOTE: Exotic pests including Karnal bunt (*Tilletia indica*) and Khapra beetle (*Trogoderma granarium*) are a threat to the Australian grains industry—report sightings immediately.

## More information

[GRDC Stored Grain Information Hub: Northern & southern regions grain storage pest control guide](#)

[GRDC Fact Sheets: Stored grain pests identification](#)

<sup>19</sup> P Burrill, P Botta, C Newman, B White, C Warrick (2013) Northern and southern regions stored grain pests—identification. Grain Storage Fact Sheet, GRDC, June 2013, <http://www.graintec.com.au/media/34527/Grain%20Storage%20Fact%20Sheet-%20Stored%20Grain%20Pests%20-%20Identification%20%28Northern%20and%20Southern%20Regions%29.pdf>

<sup>20</sup> G Daglish, A Ridley (2012) Stored grain insects: How they spread and implications for resistance. GRDC Research Update Northern Region, Spring 2012, Issue 66, <http://www.grdc.com.au/-/media/DAF5F438D9644D90B9A4FA9716B2014E.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 due to direct losses from crops damaged by frost and growers missing opportunities. Due to the variability in the incidence and severity of frost a number of management strategies should be utilised in a farm management plan.

Key points:

- The frost season in Australia has lengthened with earlier season starts and later finishes.
- 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, 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.<sup>1</sup>

### Key points

A comprehensive frost management strategy needs to be part of annual farm planning, it should include

- pre-season,
- in-crop and
- post frost event management tactics
- In some Australian production areas the risk of frost has increased due to 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 individual 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 how the crop is managed.
- 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.
- Frost damage is not always obvious and crops should be inspected within five to seven days after a suspected frost event.

<sup>1</sup> 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>;



- Methods to deal with the financial and personal impact of frost also need to be considered in a farm management plan.<sup>2</sup>

### 14.1.1 What causes frost?

In the Australian grains belt, 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 zero. 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, as soil moisture adds to the heat storage capacity of the soil.

Wind and cloud reduce the likelihood of frost by decreasing the loss of heat to the atmosphere. The extent of frost damage is determined by how quickly the temperature takes to get to zero, the length of time it stays below zero and the how far below zero it gets.<sup>3</sup>

### 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 also increases below the canopy.

Measuring temperature at Stevenson Screen height (1.2m) will not be the same as at the canopy height and the more remote the measurement is taken 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.

Temperature recorded at a local BOM site at Stevenson Screen height (standard) may or 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 general rule of thumb is that the canopy temperature is approximately 1.5 to 2.5°C lower than Stevenson Screen temperature at 1.2m at the same point in the landscape.

The most accurate method of determining paddock and crop height temperature is to use accurate loggers placed at the canopy height in crop.<sup>4</sup>

### 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 between 10 and 55 days between 1960 and 2011 and in some parts of eastern Australia the number of frost events have increased.

CSIRO analysis of climate data over this period suggests the increasing frost incidence is due to the southerly displacement and intensification of high pressure systems (sub-tropical ridge) and to heightened dry atmospheric conditions associated with more frequent El Niño conditions during this period.

The southern shifting highs bring air masses from further south than in the past. This air is very cold and contributes to frost conditions.

<sup>2</sup> 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>;

<sup>3</sup> 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>;

<sup>4</sup> 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>;

In the eastern Australian grainbelt the window of frost occurrence has broadened, so frosts are occurring both earlier and much later in the season. 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 three weeks in the Victorian grainbelt and by two weeks in the NSW grainbelt. The frost window in Western Australia and Queensland has, statistically, remained the same length, while eastern SA sites are similar to Victoria and sites in the west of SA are more like WA. Northern Victoria seems to be the epicentre of the change in frost occurrence, with some locations experiencing a broadening of the frost season by 53 days.<sup>5</sup>

#### 14.1.4 How does frost affect crops?

The ways in which frost can affect crops are complex as it has several effects on plants including cold, desiccation and freezing.

While ice melts at 0°C, the freezing temperature of water is not 0°C, pure water does not readily freeze until -40°C. Water and plant tissue supercools at temperatures below 0°C, up 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 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 sub zero 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; from cold or chilling, to desiccation and then finally freezing (Figure 1). It is a step wise response, i.e. desiccation will not occur without first getting cold damage, freezing damage will only occur after first experiencing cold and desiccation damage: Then finally the freezing damage will be random throughout a crop canopy and tissues due to the random nature of the ice nucleation and formation.

1. Cold or chilling damage - occurs when plants are exposed to temperatures less than 10°C down to -2°C (Fig. 1). 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 this 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.
2. Desiccation from ice formation occurs at temperatures from 0 to - 2°C (Fig. 1). 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 also then draws out the water from inside the cells and dehydrates the cells. The cells themselves may not necessarily freeze or have ice form inside them. This process won't necessarily kill the cells as long as the dehydration and desiccation doesn't go too far. When the ice thaws these cells can re-hydrate 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 (Fig. 1). The ice crystals physically rupture cell walls and membranes within the cells causing physical damage to 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 also susceptible at the earlier stages of booting (from Zadok Stage 45-71 Fig 2.). Losses

<sup>5</sup> 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;>

in grain yield and quality from frost primarily occur between stem elongation and late grain filling.

Pulses and canola are particularly susceptible during pod filling and losses may reflect pod wall thickness and the location of pods above or below the canopy.

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.<sup>6</sup>

### 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. As ice formation requires an ice nucleator such as bacteria or dust and rainwater contains these, when rainwater falls on a crop canopy the concentration of these nucleators is often higher. This means a slightly wet canopy from light showers will have a warmer freezing point than a dry canopy and will not supercool to as low a temperature before freezing damage occurs.<sup>7</sup>

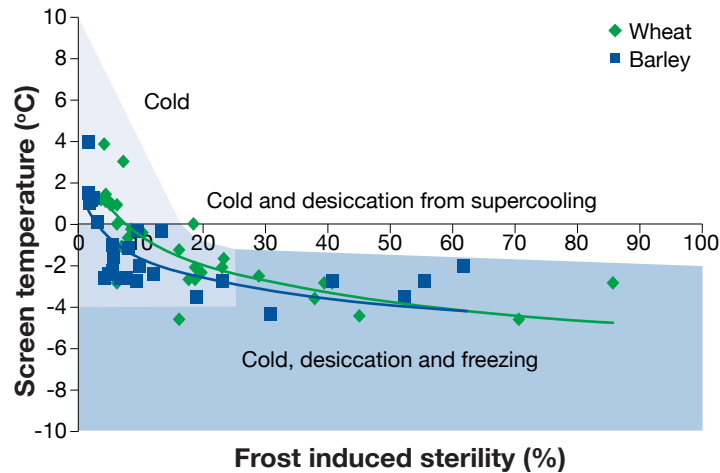


Figure 1: Average frost induced sterility in flowering heads of wheat and barley versus minimum Stevenson's screen temperature from frosts at trials from WA, SA and NSW frost nurseries 2010-2014.

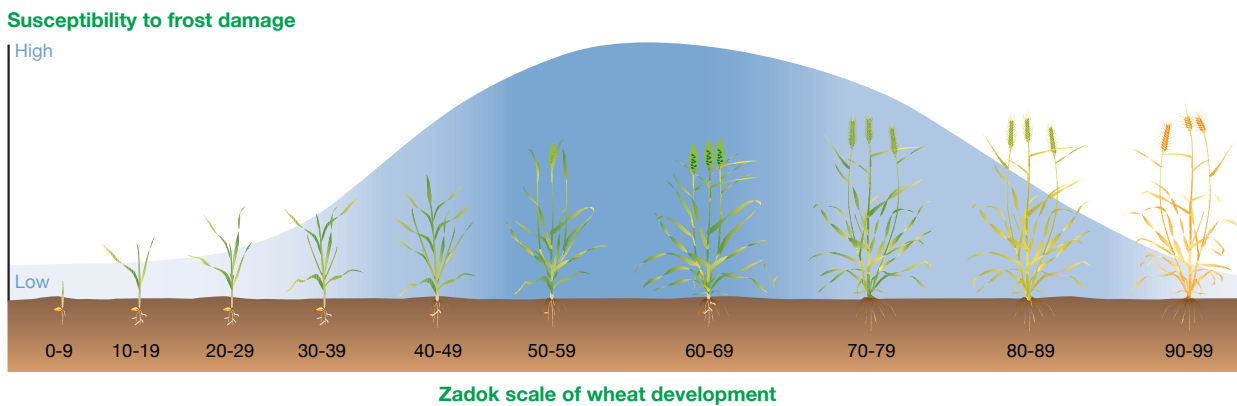


Figure 2: Susceptibility of wheat to frost during the development cycle

<sup>6</sup> 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>;

<sup>7</sup> 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>;

### 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 proactive, pre-season management tactics, in-season tactics, and strategies following the incidence of frost.<sup>8</sup>

### 14.1.7 Pre-season management tactics

There are two types of pre-season management tactics 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 tactics:*

#### **STEP 1 Assess personal approach to risk**

Consider your personal approach to risk in your business, every individual will have a different approach. As part of this process 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 due to the location and using historic seasonal records and forecasts. Spatial variability across the landscape should also be considered as cold air will flow into any lower regions. Temperature monitoring equipment, such as Tiny Tags, 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 is subject to the location of the business and skill set of the manager but the largest financial losses with frost have occurred where growers have a limited range of enterprises or crop types. Intensive cropping systems especially focused only on canola and spring wheat are often at the mercy of frost more than a diversified business; both crops are highly susceptible to frost damage.

#### **STEP 4 Zone property/paddock**

Paddocks or areas in paddocks that are prone to frost can be identified through past experience, the use of precision tools such as topographic, electromagnetic and yield maps and temperature monitors to locate susceptible zones. This can help determine the appropriate management practice to use 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.<sup>9</sup>

#### *Frost zone management tactics:*

#### **STEP 1 Consider enterprise within a zone**

The use of an identified frost zone should be carefully considered, for example using them for grazing, hay or oat production and avoiding large scale exposure to frost of highly susceptible crops like peas or expensive crops like canola. It may be prudent to sow annual or perennial pastures on regularly frosted areas in order to avoid the high costs of crop production.

<sup>8</sup> 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>;

<sup>9</sup> 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>;

**STEP 2 Review nutrient management**

Targeting fertiliser (N, P, K) on high risk paddocks and seed rates 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.

While high nitrogen rates increase yield potential it will also promote vegetative biomass production and increase the susceptibility of the crop to frost. Using conservative nitrogen rates at seeding and avoiding late top-ups appears to result in less crop damage.

It is best if crops are not deficient in potassium or copper, as this may increase susceptibility to frost events. This can be assessed from initial soil tests and with plant tissue testing.

Copper deficiency can be ameliorated with a foliar spray pre-flowering and as late as 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 potentially influence tolerance to frost. It has been shown that plants deficient in potassium are more susceptible to frost. Soils that are deficient in potassium could benefit from increasing potassium levels at the start of the growing season. However it is unlikely that there will be a benefit of extra potassium applied to plants that are not potassium deficient.

Frost tolerance can't be bought by applying extra potassium or copper to a crop that is not deficient. There is no evidence that applying other micronutrients has any impact to reduce frost damage.

**STEP 3 Modify soil heat bank**

Techniques that manipulate the storage and release of heat from the soil heat bank into the crop canopy at night are important to consider to reduce the impact of a frost event (Figure 3).<sup>10</sup>

<sup>10</sup> 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>;

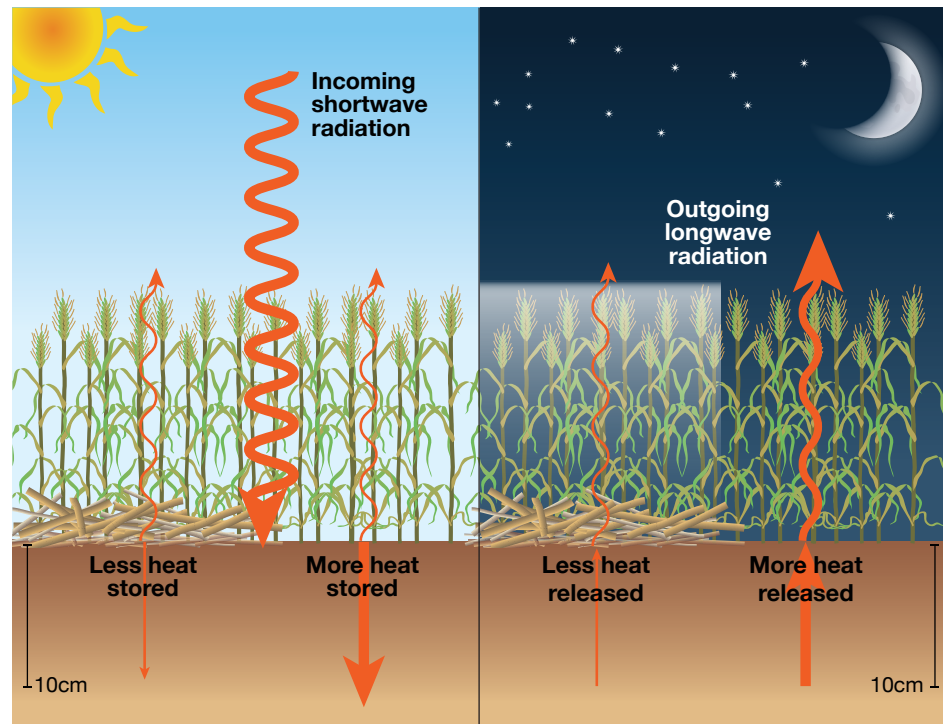


Figure 3: Soil heat bank illustrating the role in which it captures heat during the day and radiates heat into the crop canopy overnight to warm flowering heads and minimise frost damage

Agronomic practices that may assist with storing heat in the soil heat bank include:

- Practices that alleviate non wetting sands such as clay delving, mould board ploughing or spading - have multiple effects; these include 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 also prepares the surface for hay cutting should it be necessary.
- Reducing the amount of stubble - stubble loads above 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.
- Lower 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. Weed competitiveness can be an issue.
- Cross sowing crops sown twice with half the seed sown in each direction gives a more even plant density and 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. This practice, however, increases sowing costs.

#### STEP 4 Select appropriate crops

Crop selection is an important factor to consider for frost-prone paddocks. Hay harvests biomass and hence 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, but it is not known if barley and wheat have different frost tolerance during grain fill. Canola is an expensive crop to risk on frost-prone paddocks due to high input costs.

Flower Power (DAFWA) and Yield Profit are useful tools to match the flowering time of varieties to your farms prevailing conditions.

### STEP 5 Manipulate flowering time of cropping program and specific crops

When wheat is planted in frost risk areas, a good tactic is to ensure the flowering window of the cropping program is spread widely by using more than one variety and manipulating sowing date and varieties with different phenology drivers so crops flower over a wide window throughout the season. It should be noted that flowering later than the frost window will invariably result in low yields due to heat and moisture stress.

It is recommended to stage sowing dates over a 3-6 week period. If sowing just one variety, this would provide a wide flowering window. If winter wheat is sown first, then a long season spring wheat or daylength sensitive wheat, then the early maturing wheats last, the whole wheat program is set to flower over a 2 week period, potentially exposing it to more frost risk but maximising the yield potential 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.

To minimise frost risk there needs to be a mix of sowing dates, crop types and maturity types to be able to incorporate frost avoidance strategies into the cropping system. In years of severe frost, regardless of what strategy is adopted it may be difficult to prevent damage.

Trials have found that blending a short season variety with a long season variety is an effective strategy. However the same effect can be achieved by sowing one paddock with one variety and the other with another to spread risks.

Sowing at the start of a variety's preferred window will achieve higher yields at the same cost as sowing late. Sowing time therefore remains a major driver of yield in all crops with the primary objective to achieve a balance between crops flowering after the risk of frost has passed but before the onset of heat stress. The loss of yield from 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. Consider using wheat and barley varieties that have lower susceptibility to frost during flowering to manage frost risk of the cropping program while maximising yield potential. There is no point selecting less susceptible varieties for the whole cropping program if there is an opportunity cost of lower yield without frost.

Preliminary ranking information for current wheat and barley varieties for susceptibility to reproductive frost is available from the National Variety Trial website ([www.nvtonline.com.au](http://www.nvtonline.com.au)). Use this information to fine tune frost risk of new varieties after they have been selected. A new variety should be managed based on how known varieties of similar ranking are currently managed.

Figure 4 shows an example of the ranking of adapted wheat varieties for the Western Region. A grower in the WA Upper Great Southern may be considering how to incorporate Corack and Scout into their cropping program to replace Wyalkatchem and Yitpi. From a frost risk management point of view, Corack can be treated in the same way as Wyalkatchem or Mace. Given its similar sowing/flowering time response to Mace it can essentially be treated the same in terms of sowing/flowering time and position in the landscape. Scout on the other hand although similar in frost performance to Yitpi flowers around 5-7 days earlier so may need to be sown slightly later than Yitpi to manage frost risk comparably to Yitpi.

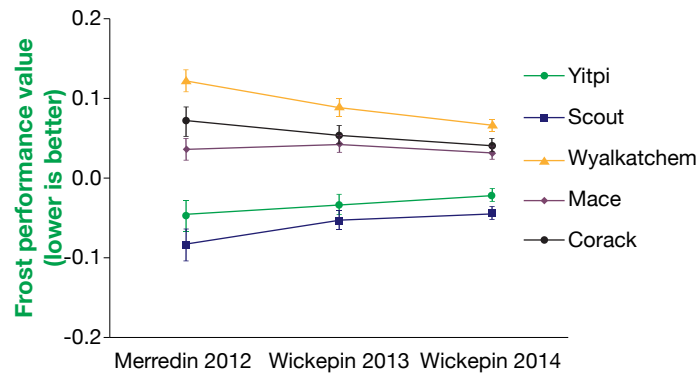


Figure 4: Rankings of regionally adapted wheat varieties for frost susceptibility in the Western Region.

Figure 5 shows an example of the ranking of adapted wheat varieties for the low to medium rainfall cropping areas of the Southern Region. Mace is a widely grown and adapted high yielding variety for most of the area. Emu Rock, Yitpi and Scout are all slightly better than Mace in their ability to yield when there are flowering frosts. Emu Rock has similar maturity to Mace while Scout is slightly later. Yitpi has some daylength sensitivity so can be sown earlier without causing earlier maturity. There could be some advantage in adopting an area of Emu Rock, Scout or Yitpi to reduce the overall farm susceptibility compared to growing all Mace.

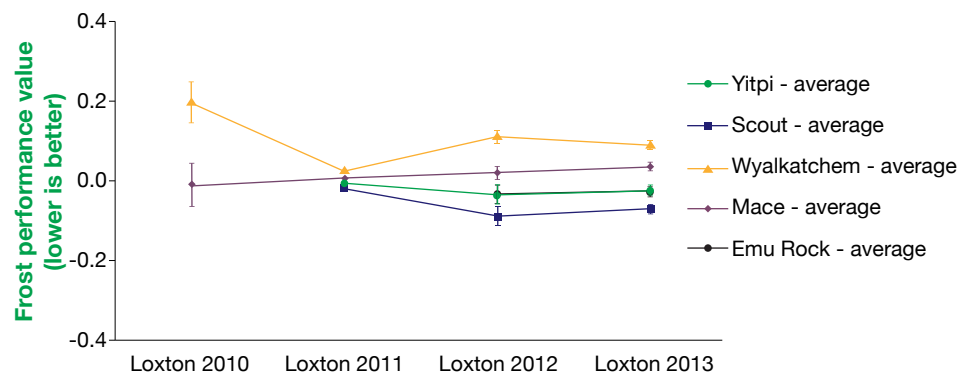


Figure 5: Frost Value graph for five wheat varieties tested at Loxton South Australia. Each FV for each variety is presented along with prediction standard error bars. The number of tagging events is indicated in brackets for each site/year. Lower FVs are better.

### 14.1.8 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 southern WA and SA have shown grazing wheat crops in winter to delay flowering can reduce grain yield losses from spring frosts by extending the flowering date. Additionally these crops can provide extra fodder for livestock.

This management tactic can be used as a tool to not only 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 crop four-five leaf stage or even earlier) and graze hard for a short period. Fourteen days grazing delays flowering by about seven days. Grazing after first node (Z31) will significantly delay flowering and crop yield. High stock numbers are often required.



### Extra nutrients

Conservative input strategies should be adopted for frost prone area and minimal or no additional nutrients should be applied during the season. Manage nitrogen to frost risk. Avoid late nitrogen top-ups in zones and paddocks which have been identified during pre-season planning as having higher frost risk.

Copper is the only exception, tissue test for copper during tillering and apply foliar copper at booting if tissue samples are identified as marginal.<sup>11</sup>

#### 14.1.9 Post frost event - management tactics

Once a frost event (especially at or after flowering) has occurred, the first step is to obtain an estimate of the yield loss suffered by inspecting the affected crop and randomly collecting a sample of heads to estimate the yield loss incurred.

After the level of frost damage is estimated the next step is to consider options for the frost damaged crop.

Tillers already formed but lower in the canopy may become important and new tillers can grow after frost damage has been incurred, depending on the location and severity of the damage. These compensatory tillers will have delayed maturity, but where soil moisture reserves are high, or its early in the season they may be able to contribute to grain yield.

##### OPTION 1 Take through to harvest

If the frost is prior to or around (growth stage) GS31 to GS32, most cereals can produce new tillers to compensate for damaged plants provided spring rainfall is adequate. A later frost is more concerning, especially for crops such as wheat and barley, as there is no time for compensatory growth. The required grain yield to recover the costs of harvesting should be determined using gross margins.

##### OPTION 2 Cut and bale

This is an option when late frosts occur during flowering and through grain fill. Assess crops for hay quality within a few days of a frost event and be prepared to cut a larger than intended area for hay as grain yield may be reduced. Hay can also be a good management strategy to reduce stubble, weed seed bank and disease loads for the coming season. This may allow more rotational options in the following season to recover financially from frost, for example to go back with cereal on cereal in paddocks cut early for hay. Hay can be an expensive exercise, growers should have a clear path to market or a use for the hay on farm before committing costs to this practice.

##### OPTION 3 Graze

Grazing is an option after a late frost, when there is little or no chance of plant recovery, or when hay is not an option because of farm set-up or limited marketing opportunities. Spray-topping for weed seed control may also be incorporated, especially if the paddock will be sown to crop the next year.

##### OPTION 4 Green or brown manure

Ploughing in the green crop or spraying out any remaining crop and weeds will return organic matter and nutrients to the soil, manage crop residues and improve soil fertility and structure. The economics need to be considered carefully.

##### OPTION 5 Crop topping

Accept the yield loss but ensure annual weeds are controlled for future years. Crop topping of frosted areas may still be a worthwhile practice even if harvest has been abandoned.<sup>12</sup>

<sup>11</sup> 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>;

<sup>12</sup> 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>;

### 14.1.10 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 they become less frost susceptible. If affected during -

flowering: the grain is aborted and yield is reduced but there is rarely any negative impacts on quality of remaining grain.

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.

milk stage of development: grains may continue to develop, but will be light and shrivelled. They usually have a low hectolitre weight and high screenings, but this can usually be minimised by adjusting header settings.

late dough stage: can result in wrinkly/scalloped grains. Again, these may have a 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 included in the category 'Dry Green, Sappy and Frost Distorted', for which there is a maximum limit of 1% in total. Grain containing over 1% but less than 10% Frosted Grain is classified as Australian General Purpose (AGP). Any grain exceeding this level will be classified as feed and is only suitable for stock feed.

Higher classification of frost affected grain may be achieved by cleaning grain but the capacity and economics of doing this needs to be carefully considered.<sup>13</sup>

### 14.1.11 Retaining seed from frosted crops

Grain that forms when a flowering frost occurs is often plump and makes good quality seed however where frost occurs during grain fill variable effects can impact the germination and establishment of this damaged grains.

Even after grading, frosted grain can have 20-50% lower crop establishment than unfrosted grain the following season. As a result growers need to retain more seed than normal, sow into an optimum seed bed and increase seeding rate to compensate for lower crop germination and vigour of frosted grain.

Growers are advised to:

1. Retain and grade seed only from less frost damaged areas. Also retain slightly more seed than normal, depending on extent of damage (screenings/ frost distorted grain counts) as seeding rate may need to be increased.
2. Test germination prior to sowing and adjust seeding rates accordingly to ensure uniform crop establishment
3. Do not plan to retain frost affected seed for more than a year.<sup>14</sup>

### 14.1.12 Recovering from frost

Dealing with the financial 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.
- Access the physical, financial and people situation factually so that decisions are based on the best information.

<sup>13</sup> 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>;

<sup>14</sup> 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>;

- Develop alternate strategies for dealing with frosted crops in future programs and 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 don't get caught up in negativity and 'pub talk'.
- Frost can be easily forgotten from one year to the next. Don't let early rain distract the plans to spread or reduce risk. <sup>15</sup>

### 14.1.13 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;

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. <sup>16</sup>

#### Useful tools

Weather apps: see AgExcellence Alliance for a review <http://agex.org.au/>

Plant development apps (eg MyCrop, DAFWA FlowerPower)

Temperature monitors for example see [http://www.hobodataloggers.com.au/outpost-frost-alarm-system-3?utm\\_source=HOBO+Data+Logging+E-News+June+2015&utm\\_campaign=Data+Logging+E-News+June+2015&utm\\_medium=email](http://www.hobodataloggers.com.au/outpost-frost-alarm-system-3?utm_source=HOBO+Data+Logging+E-News+June+2015&utm_campaign=Data+Logging+E-News+June+2015&utm_medium=email)

### 14.1.14 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 first and, if damaged, continue the examination in other parts of the paddock. Often the most susceptible parts are the lowest points or at the base of a slope.
- Walk through the crop and examine a whole plant every 20 or 30 paces or 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.

<sup>15</sup> 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>;

<sup>16</sup> 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>;

- If the head has not emerged from the boot, check to see if the head is damaged. You will need to carefully dissect the plant from the top down to find the head of the plant (with a sharp knife).
- 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 the grain is developing. See photos below for what is healthy.
- Tag a few heads with plastic insulation tape and note the stage of grain fill. Return a few days later to determine if grain development and grain filling is continuing. Normal grain should be extending at approximately 1mm every 2 days until the full length is achieved.<sup>17</sup>

### 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 to allow for management decisions to be made. The pollen and anthers are the 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 any signs of damage. An inspection after 2 days may show anther damage and after 4 days should reveal whether grain development has been affected. It is important to note that crops will often be affected unevenly and not all plants will show obvious symptoms.

Carefully remove the leaf sheath from around the stem and check above the nodes below the head for symptoms on the peduncle or stem of the plant. To inspect heads, peel back the glumes to inspect the reproductive structures or developing grain inside. Inspect spikelets half way up representative heads as this is the most developed part and then above and below the centre. A hand lens may be of benefit and digital microscopes are of great value. 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 wheat crop with an estimated yield of 2.5 t/ha is frosted and a sample of 20 wheat heads is taken from the crop. Out of the 20 heads, 12 are completely filled and 8 half filled with grain. This would represent a yield loss of:

$$8/20 \times 50\% \times 2500 = 500\text{kg/ha yield loss.}^{18}$$

### Juvenile frost damage

While frost damage frequently occurs to crops in the juvenile stage, in parts of Australia, there is usually little or no yield loss as there is ample time for the plant to compensate with new leaves or tillers.

The worst damage is when the growing point of the plant is above ground level and results from 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. While 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.<sup>19</sup>

<sup>17</sup> 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>;

<sup>18</sup> 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>;

<sup>19</sup> 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>;

### 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 (Z30-39) the developing head and stems can still be frozen by very severe frosts (Figure 6.)

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 6a) and the crop will re-tiller.

Frost damage to the stem may be evident as blistering and bleaching of the stem internodes (Figure 6a). Sometimes this can be associated with damage to the head, but not always as in Figure 3, where the stem is damaged but not the developing head.

Experience in the 2014 season indicates crops can re-tiller and achieve reasonable yield levels, providing temperatures are favourable and either soil moisture is good or spring rainfall is adequate.<sup>20</sup>



Figure 6: Damage to developing wheat heads from frost at stem elongation (a) one healthy head (left) and five frosted heads (FS, frosted stem). (b) Close up of a healthy wheat head. Frost occurred at ~Z32, and photos were taken at ~Z37, 2–3 weeks later. (Photos: (a) Karl Moore and (b) Ben Biddulph, DAFWA)

<sup>20</sup> 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 7: Damage to the developing barley head from frost at stem elongation ~Z35, frosted head left (F) and healthy head right (H). Photos were taken at 2-3 weeks after the frost at ~Z49. (Photo: Ben Biddulph, DAFWA)



Figure 8: Damage to the stem internodes, but viable head. (Photo: Ben Biddulph, DAFWA)

### Head damage: cold damage to developing head prior to head emergence

- At the very early stage of development, prior to head emergence at Z51 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 (Z39-45) and early pollen development (Z45-65), the head or particular florets can stop development altogether and abort.
- The damage at this stage is quite distinct and heads emerge with a pale undeveloped colour from white (Z39; Figure 9a) to light green (Z51; Figure 9c)

depending on the stage of pollen development when 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 9: 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). Photo taken at flowering after head emergence, 2–3 weeks after the frost events. (Photo: 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 (Z51 onwards) can occur when canopy temperature drops to 0°C or below.

Damage may not be visually obvious for several days unless the heads are closely inspected and the reproductive parts inside the florets are inspected for damage as in Figures 10 and 11. A digital microscope is useful for aiding identification.<sup>21</sup>



Figure 10: 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)

<sup>21</sup> 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>;



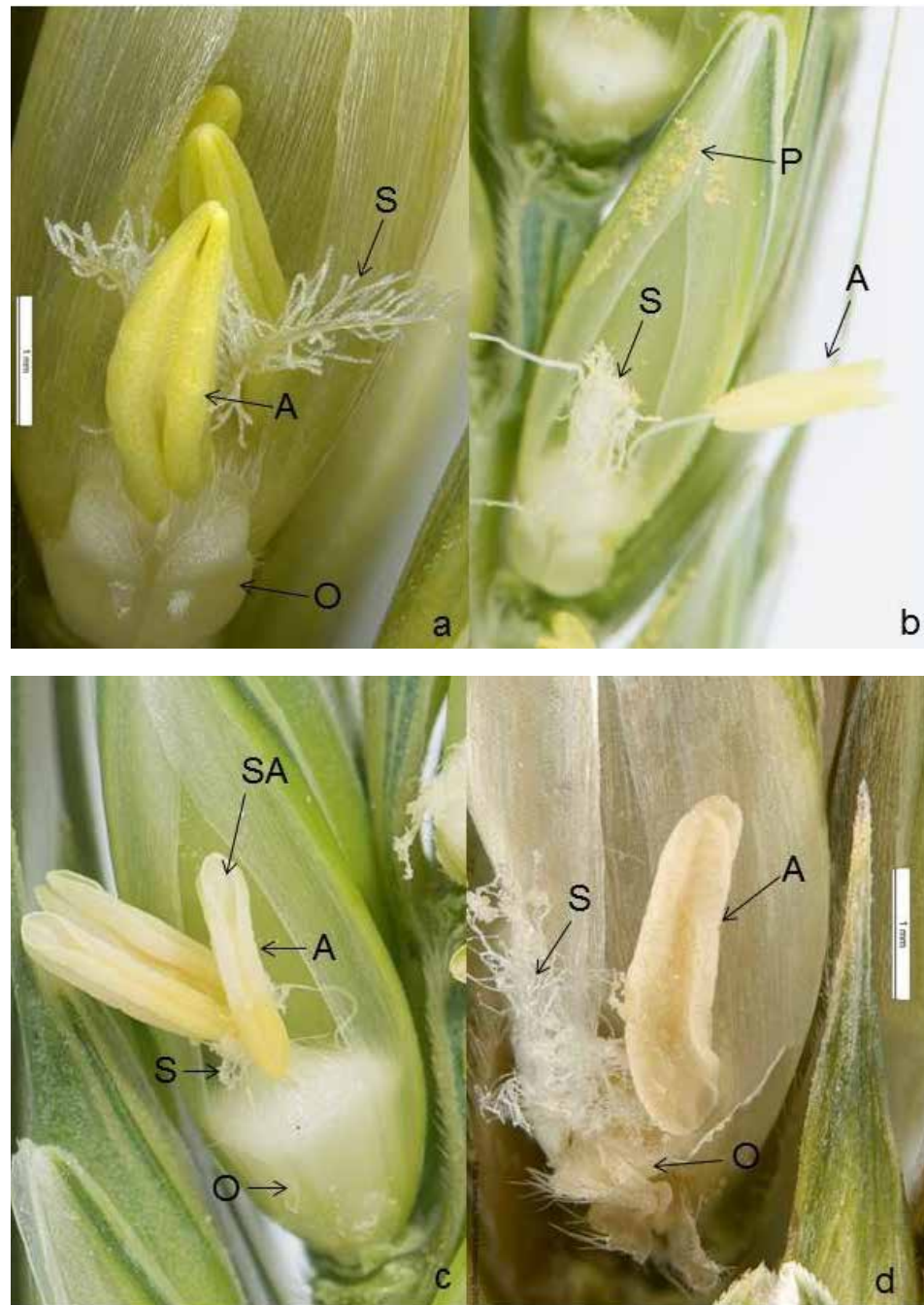


Figure 11: (a) Healthy floret about to flower: anthers (A), stigmas (S) and ovaries (O) of wheat within a floret. (b) Freshly fertilised floret: pollen (P). (c) Fertilised and swollen ovule: split anthers (SA). (d) Frosted floret. Photo of frosted floret taken at GS70.2 of heads frosted just prior to flowering (GS61). (Photo: Pia Scanlon, DAFWA)

During normal head development, immature anthers are light green, turning yellow on maturity just prior to flowering (Figure 11a) and prior to extruding from the floret.

Healthy anthers turn from yellow prior to pollen release (Figure 11a) to white after they have released the yellow pollen (Figure 11b and c)

After a frost event, the anther may remain light green to yellow for 1 to 2 days before turning white and shrivelled as in Figure 11d. Often anthers have a water soaked appearance (similar to frozen lettuce leaves)

The real tell-tale sign of frost damage is white anthers and ovules which are not swollen or developing (Figure 11b and 11d).

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 11a). A fertilised stigma has a light coating of yellow pollen cells and curls up (Figure 11b and c). While a frost affected, un-fertilised stigma will become off-white to brown and shrivelled in appearance (Figure 11d).

This damage at flowering is mainly from the cold and 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 12).

### *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/ bleached appearance several days after the frost (Figure 12).

Blighting usually affects only a small proportion of the heads as in Figure 7, but is also often associated frost damage to the reproductive structures inside which requires closer inspection as in Figure 12.

After about a week, cold, desiccation and freezing head damage starts to become more obvious, and may not require dissection as in Figure 12. As a result of the low fertilisation of the grain the whole heads beginning 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 which have been frozen turn white.

As the florets do not fill with grain, 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 as there is no grain development and grain filling.<sup>22</sup>



Figure 12: 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)

<sup>22</sup> 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>;

### 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. Remember though that flowering is not synchronous so while 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 Z70.2- Z79), the developing grains may be frozen and do not continue to develop. It turns a white to grey colour and becomes shrivelled and dry (Figure 9) instead of plump and full of clear sugar filled solution (Figure 14). These grains are not normally retained in a header sample and often shatter easily at maturity.

When frosted during dough development and grain filling (Figure 8; GF Z80-89) the grains often don't abort, but become scalloped (Figure 13) and continue to develop. Often they initially develop a dark green, water soaked appearance that is visible through the outside of the grain. By squeezing these grains at the early dough stage (Z81), the contents will be grey and liquid instead of white, slippery and viscous.

As frosts often follow the cycle of weather patterns, crops are often frosted at several successive stages of development and will exhibit a combination of different symptoms as seen in Figure 8 where the same head has damage from frost at flowering (Z61), grain development (Z70.8) and early grain filling (Z81). These symptoms also change in appearance over time depending on the time since the frost damage occurred Figure 9.

The effect of frost damage over an entire crop is often the cumulative effect of several frosts that the crop has incurred during its' development over a 3-4 week window.

Wheat that has been frosted at the grain filling stages are a little more resilient to the effects of frost, often showing 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.

It is not recommended to keep frost affected grain for the following year, as germination may be reduced.

It is not recommended to keep frost affected grain for the following year, as germination may be reduced. <sup>23</sup>

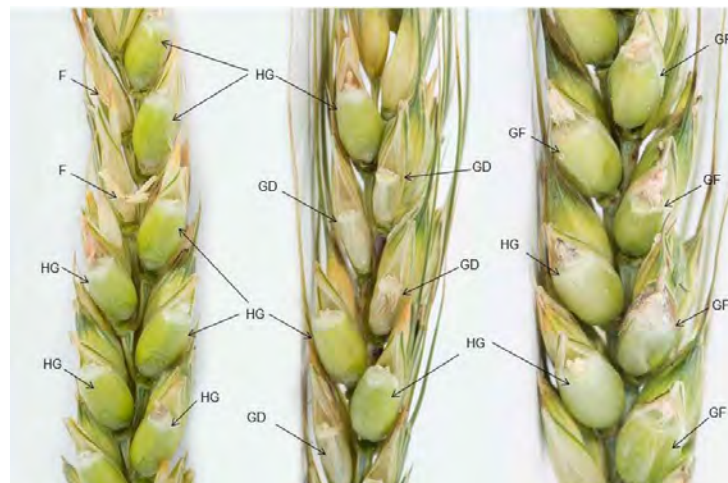


Figure 13: Wheat head that has been frosted at flowering (GS65; F) and at grain development (GS70.8; GD), and partially frosted during grain filling (GS81; GF). Frost-affected grains starting to shrivel (GD) to form a pinched or scalloped appearance (GF) compared with healthy grains (HG). Frosts occurred at ~GS65, GS70.8 and GS81, and the photo was taken at ~GS83. (Photo: Pia Scanlon, DAFWA)

<sup>23</sup> 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 14: 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 15: Grains collected at maturity that are (a, b) unfrosted; (c) frosted at GS70.5-71; (d) GS73-75; (e) GS75-79; (f) GS81-83; (g) GS83-87.

*Stem damage after flowering: freezing damage to the peduncle after head emergence during grain development and grain filling*

At and after ear peep (Z51) the peduncle is susceptible to freezing damage.

There are two types of peduncle damage 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 ~Z51–55 where the rain allows a small amount of water to collect inside the leaf sheath surrounding the most undeveloped section of the peduncle. (Figure 16).



Figure 16: 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).



Figure 17: Peduncle stem damage showing light-green region (S) and bleached heads with infertile florets (B).

Initially, 1–3d 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 11a). This is common for Type 1 and Type 2 damage. Sometimes a slightly less severe symptom of Type 1 will be blistering.

3–7d after the frost event the head and peduncle can't be pulled from the standing crop for Type 2 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 a result of lignification and “scaring” of the frosted section of the peduncle (Figure 11b close up). This section is often light green in colour and the surface of the peduncle is rough in this area. The head and peduncle can be easily pulled out for Type 1 and distinct narrowing of the peduncle just above the node will be obvious.

Around 5–10d after the frost event the stem (or peduncle) when frosted will have a light green or white ring around the stem for Type 2 (Figure 11b and 12) and will feel rough and hard.

If the stem frost is not very severe, and the reproductive tissues have not been destroyed by the same frost event then the plants may recover and achieve a 20–40% reduced yield, as sugar and water will continue to be taken up by the developing head. Recovery and compensation is greatest when there is ample soil water and mild temperatures. Severe Type 1 peduncle frosts can result in 100% yield loss. It is possible to test the viability of the tissue by taking a sample of wheat heads together with their stalks, cut cleanly with a knife low on the plant and placing them in a blue food dye solution overnight. If the tissue is viable the heads will turn blue and grain fill may proceed normally.

In more severely affected stems, they can become distorted and sugar and water flow may be restricted to the head, reducing grain fill 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.<sup>24</sup>

<sup>24</sup> 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>;

### The frost window

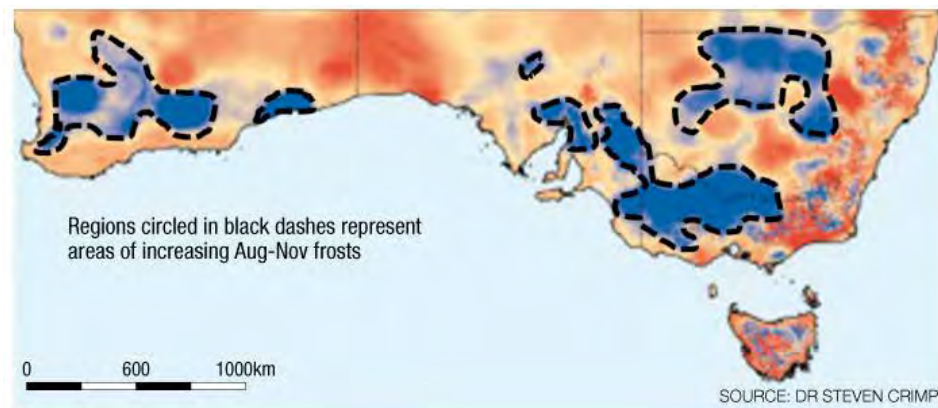


Figure 18: Regions of increasing August–November frosts.

The frost window has lengthened by 3 weeks in the Victorian grainbelt and by 2 weeks in the New South Wales grainbelt (Figure 18). Statistically, Western Australia has remained the same. Sites in eastern South Australia 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. Analysis of long-term temperature data for Longerenong in the Victorian Wimmera indicates that the incidence of moderate (2°C) and extreme (0°C) frosts during the wheat flowering window has increased in the past 15 years (Figure 19).<sup>25</sup>

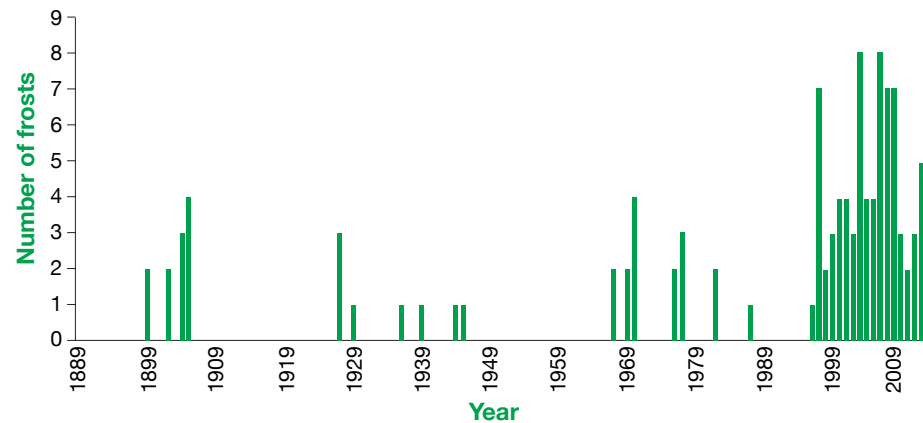


Figure 19: Historic number of frosts in the flowering window 20 September–30 October for Yitpi, Longerenong, Victoria.

### Useful tools

Weather apps: see [AgExcellence Alliance](#), [ClimiMate](#), [Meteye](#), [DAFWA weather stations app](#).

Plant development apps: [MyCrop](#), [DAFWA FlowerPower](#)

Temperature monitors: [HOBO Data Loggers](#)

#### 14.1.15 National Frost Initiative

The objective of the Grain Research and Development'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.

<sup>25</sup> GRDC (2014) Frost risk on the rise despite warmer climate. Ground Cover 109, GRDC 3 March 2014, <http://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109/Frost-risk-on-the-rise-despite-warmer-climate>

- 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.<sup>26</sup>

## 14.2 Waterlogging–flooding issues

### 14.2.1 Winter cereal pathology

Three drivers influence the incidence of plant disease:

- the host
- the environment
- the pathogen

Aspects of host management that might promote disease are the growing of susceptible crop varieties, and widespread and sequential sowings of hosts susceptible to specific pathogens.

The environment influences disease incidence through moisture (both the frequency and duration of events), temperature and wind.

For disease to occur, the pathogen must have virulence to the particular variety, inoculum must be available and easily transported, and favourable conditions are needed for infection and disease development.<sup>27</sup>

#### *Legacy of floods and rain*

The legacy of the 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 particularly applies to 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 inspection of plants. Leaf and stem rusts produce visible pustules on leaves. Stripe rust survives as dormant mycelium, with spores not being produced until temperatures favour disease development. Presence of leaf spots is recognised by fruiting bodies (pseudothecia) on straw and lesions on volunteers. Head blights produce fruiting bodies (perithecia) on straw, whereas crown rot survives mainly as mycelium in straw. Soilborne nematodes are detected through soil tests.<sup>28</sup>

<sup>26</sup> 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>;

<sup>27</sup> 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>

<sup>28</sup> 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>



## **i** More information

[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 scale](#)

[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 options

Management options for disease control include elimination of volunteers, if possible producing a 4-week period that is totally host-free, crop rotation with non-hosts, growing resistant varieties, reduction of stubble, and fungicides.

Fungicides are far more effective as protectants than as 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. Remember that fungicides 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.<sup>29</sup>

## Strategies

The incidence and severity of disease will depend on the environment, but with known, 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<sup>30</sup>

## 14.2.2 Nutritional and structural impact of flooding on soil

A temporary loss of soil structure prevents clay particles from aggregating and forming channels for water infiltration, so despite flooding, some soil moisture profiles might not be as full as expected. This reduction in infiltration is also affected by which crop was grown most recently, with persistent roots forming channels in the soil, aiding water entry. Cultivation prior to, or during, planting of the next crop, will help to break up surface crusting.

Flooding also affects nutrient levels. Flooding and long periods of waterlogging have resulted in the depletion of nutrients. Nitrogen levels are very low in many soils tested. Soil testing has shown that N has been lost throughout the entire soil profile in many cases. It appears to have been denitrified and lost from the system. Very little has been leached through the profile and deposited at depth.<sup>31</sup>

## Soil testing

Ideally, soil testing should be performed at the same place each time, and on the dominant soil type of the paddock. In most years, this information, combined with yield and protein levels, will guide N requirements, but after a flood year, requirements are

<sup>29</sup> 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>

<sup>30</sup> 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>

<sup>31</sup> DAF Qld (2013) Nutritional and structural impact of flooding on soil. 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/nutritional-and-structural-impact-of-flooding-on-soil>

very different. Placement of N fertiliser is important, with application on alternate rows close to planting time being a good option.<sup>32</sup>

### 14.2.3 Soil erosion and waterlogging due to flooding—preventing future damage

Several approaches can be used to prevent post-flooding damage. Contours running down a hill generally spread the flow of water and reduce flow rates. Wheel tracks can be used like raised beds to assist drainage. These wheel tracks need to be maintained and managed for effectiveness. Wide tyres for spraying and tracks for harvesters and tractors are options to reduce compaction.

### 14.2.4 Weed management following floods

Floodwater affects soil, stubble/trash, weed seed and plant movement. Differences may have been seen between conventional and minimum tillage farming systems due to differences in groundcover, soil type and, ultimately, intensity of floodwater. Because of flooding, growers might expect to see new weed incursions and removal of topsoil.

New weeds could be species not previously seen on a property, or new species in specific fields from other fields or non-cultivated areas. There is also the potential for the introduction and movement of herbicide-resistant weeds. The removal of topsoil could lead to exposure of previously buried seed and, hence, the resurrection of buried problems. It is hard to predict where weed seeds will settle, but a concentration is likely where water and trash has settled.<sup>33</sup>

#### *Potential problem weeds*

Species of weeds in which herbicide resistance has been identified in the northern agricultural region include wild oats, sowthistle, fleabane, barnyard grass and liverseed grass. The problem is not currently widespread.<sup>34</sup>

#### *Implications for the coming season*

Integrated weed management principles still apply. These principles include diligent monitoring, targeting small weeds with robust rates of herbicide, rotating herbicides with different modes of action, and preventing seedset and seedbank replenishment. This approach will prevent herbicide resistance from becoming a problem.

For cropping, aim for a clean start with effective knockdown control (e.g. using a double-knock strategy). Use residual herbicides to minimise in-crop weed emergences. To control weeds in-crop, grow a competitive crop and use correct application and timing of in-crop herbicides. Stop seedset on survivors after harvest.

In fallows, weed seedlings should be effectively controlled with robust herbicide rates and/or a double-knock strategy. An early application of a residual herbicide will minimise subsequent flushes. Be diligent in control of survivors of herbicide applications.

In non-crop areas, seed may have been captured around fencelines and sheds, and these may become sources of ongoing infections. Monitor these areas and stop seedset.<sup>35</sup>

<sup>32</sup> DAF Qld (2013) Nutritional and structural impact of flooding on soil. 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/nutritional-and-structural-impact-of-flooding-on-soil>

<sup>33</sup> DAFF (2011) Weed management following floods. 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/weed-management-following-floods>

<sup>34</sup> DAFF (2011) Weed management following floods. 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/weed-management-following-floods>

<sup>35</sup> DAF Qld (2011) Weed management following floods. 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/weed-management-following-floods>

## **i** More information

[Research paper: Cultivar and environmental effects on quality characters in wheat. II. Protein](#)

[Research paper: The impact of temperature variability on wheat yields](#)

[Research paper: Effects of zinc on photosynthesis and yield of wheat under heat stress](#)

[GRDC Fact Sheets: Time of sowing](#)

[Research paper: Association between wheat yield and temperature in south-eastern Australia](#)

[Research paper: Heat waves and wheat growth under a future climate](#)

[Research paper: Simulating the impact of extreme heat and frost events](#)

## 14.3 Heat stress

Heat is a key abiotic stress. The effects of heat on grain yield are as important as effects of drought and frost. Varieties that are better adapted also generally perform better in heat-stress conditions.

Heat stress affects crop and cereal production in all regions of the Australian wheatbelt. It can have significant effects on grain yield and productivity, with potential losses equal to, and potentially greater than, other abiotic stress such as drought and frost. Controlled environment studies have established that a 3–5% reduction in grain yield of wheat can occur for every 1°C increase in average temperature above 15°C. Field data suggest that yield losses can be ~190 kg/ha for every 1°C rise in average temperature, in some situations having a more severe effect on yield loss than water availability.

The reproductive stages of growth have greater sensitivity to elevated temperatures, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seedset, reduced duration of grainfill, and reduced grain size, all ultimately leading to reduced grain yield. Such elevated temperatures are a normal, largely unavoidable occurrence during the reproductive phase of Australian crops in September and October.<sup>36</sup>

<sup>36</sup> P Telfer, J Edwards, H Kuchel, J Reinheimer, D Bennett (2013) Heat stress tolerance of wheat. GRDC Update Papers, 7 February 2013, <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Heat-stress-tolerance-of-wheat>

## SECTION 15

# Marketing

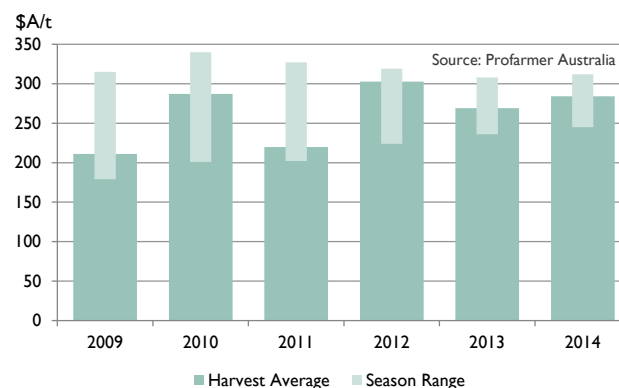
The final step in generating farm income is converting the tonnes of grain produced per hectare into dollars at the farm gate. This section provides best in-class marketing guidelines for managing price variability to protect income and cash flow.

## 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 variability and costs can be used to manage and overcome price uncertainty.



**Note to figure:**  
Pt Adelaide APW1 wheat prices have varied A\$60-\$140/t over the past 6 years (25-65% variability). For a property producing 2,000 tonne of wheat this means \$120,000-\$280,000 difference in income depending on price management skill.

Figure 1: Annual price variation (season average and range) for Port Adelaide Australian Premium White 1 (APW1) wheat.

### 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:

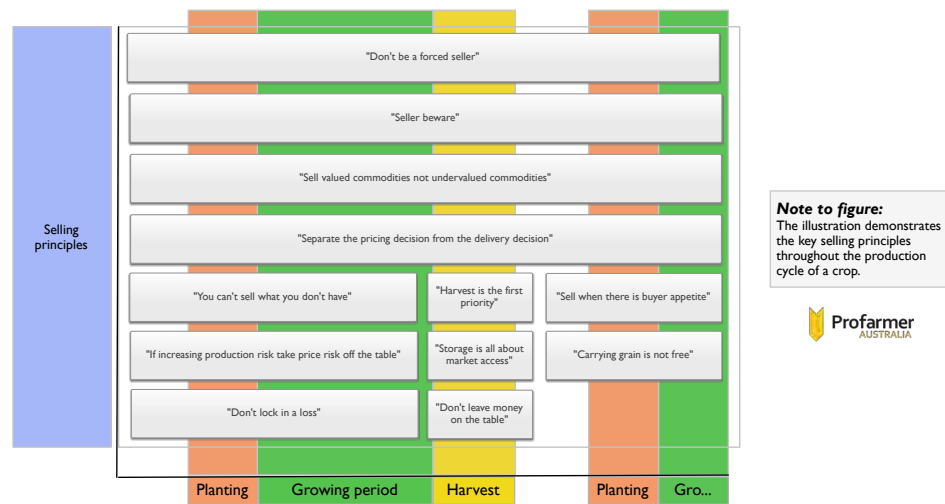
- production risk
- a target price based on cost of production and a desired profit margin
- business cash-flow requirements

### 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.



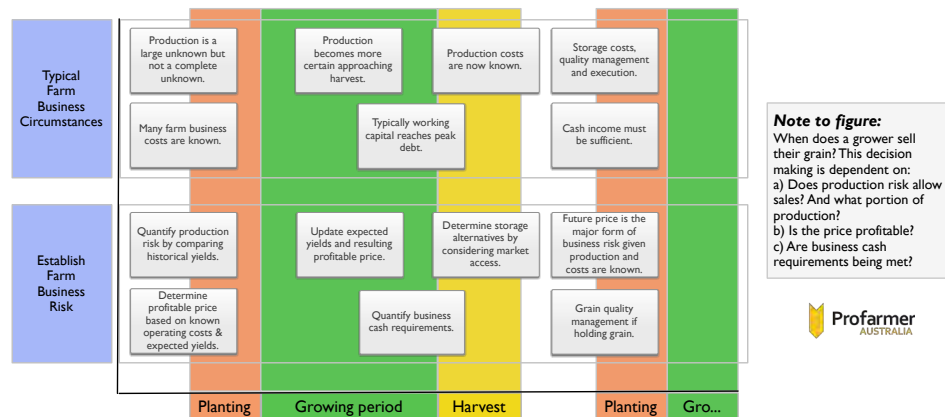
**Note to figure:**  
The illustration demonstrates the key selling principles throughout the production cycle of a crop.



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.



**Note to figure:**  
When does a grower sell their grain? This decision making is dependent on:  
a) Does production risk allow sales? And what portion of production?  
b) Is the price profitable?  
c) Are business cash requirements being met?



Figure 3: Typical farm business circumstances and risk.

### Production risk profile of the farm

Production risk is the level of certainty 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 over-committing production.

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

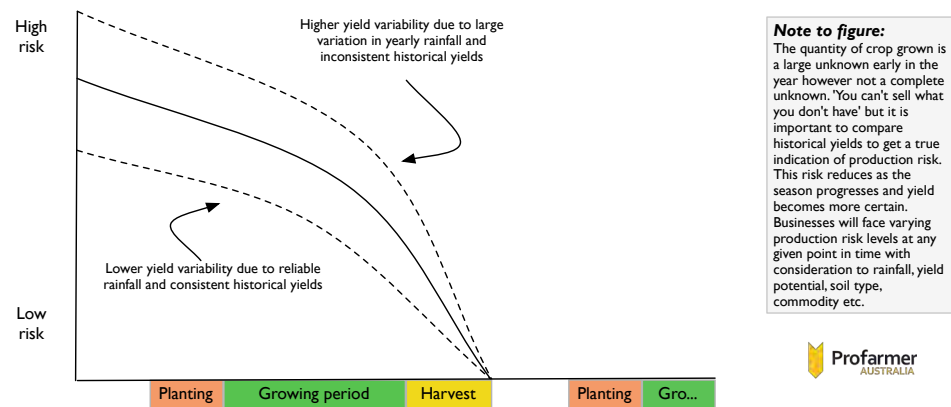


Figure 4: Typical production risk profile of a farm operation.

### 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.

Estimating cost of production - Wheat	
Planted Area	1,200 ha
Estimate Yield	2.85 t/ha
Estimated Production	3,420 t
Fixed costs	
Insurance and General Expenses	\$100,000
Finance	\$80,000
Depreciation/Capital Replacement	\$70,000
Drawings	\$60,000
Other	\$30,000
Variable costs	
Seed and sowing	\$48,000
Fertiliser and application	\$156,000
Herbicide and application	\$78,000
Insect/fungicide and application	\$36,000
Harvest costs	\$48,000
Crop insurance	\$18,000
Total fixed and variable costs	\$724,000
Per Tonne Equivalent (Total costs + Estimated production)	\$212 /t
Per tonne costs	
Levies	\$3 /t
Cartage	\$12 /t
Freight to Port	\$22 /t
Total per tonne costs	\$37 /t
Cost of production Port track equiv	\$248.70
Target profit (ie 20%)	\$50.00
<b>Target price (port equiv)</b>	<b>\$298.70</b>

Step 1: Estimate your production potential. The more uncertain your production is, the more conservative the yield estimate should be. As yield falls, your cost of production per tonne will rise.

Step 2: Attribute your fixed farm business costs. In this instance if 1,200 ha reflects 1/3 of the farm enterprise, we have attributed 1/3 fixed costs. There are a number of methods for doing this (see M Krause "Farming your Business") but the most important thing is that in the end all costs are accounted for.

Step 3: Calculate all the variable costs attributed to producing that crop. This can also be expressed as \$ per ha x planted area.

Step 4: Add together fixed and variable costs and divide by estimated production

Step 5: Add on the "per tonne" costs like levies and freight.

Step 6: Add the "per tonne" costs to the fixed and variable per tonne costs calculated at step 4.

Step 7: Add a desired profit margin to arrive at the port equivalent target profitable price.

Figure 5: Steps to calculate an estimated profitable price for wheat.

The GRDC manual '[Farming the business](#)' also provides a cost-of-production template and tips on skills required for grain selling, as opposed to grain marketing.<sup>1</sup>

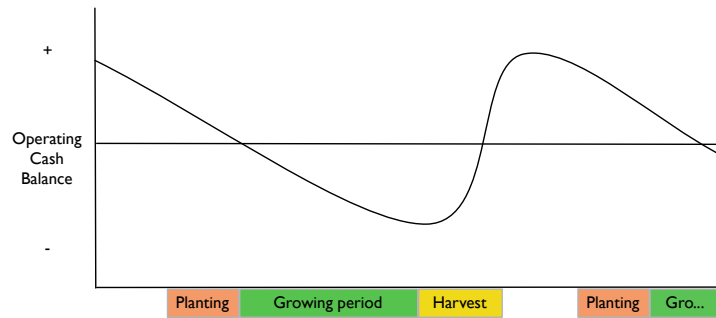
### Income requirements

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.

<sup>1</sup> M Krause (2014) Farming the business. Sowing for your future. GRDC, <http://www.grdc.com.au/FarmingTheBusiness>

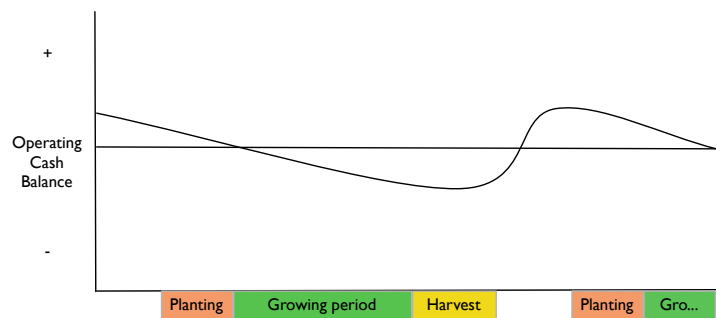


**Note to figure:**  
The chart illustrates the operating cash flow of a typical farm assuming a heavy reliance on cash sales at harvest. Costs are incurred during the season to grow the crop, resulting in peak operating debt levels at or near harvest. Hence at harvest there is often a cash injection 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.



**Note to figure:**  
By spreading sales throughout the year a grower may not be as reliant on executing sales at harvest time in order to generate required cash flow for the business. This provides a greater ability to capture pricing opportunities in contrast to executing sales in order to fulfil cash requirements.



In this scenario peak cash surplus starts lower and peak cash debt is higher

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

Figure 8 provides a summary of when different methods of price management are suited for the majority of farm businesses.

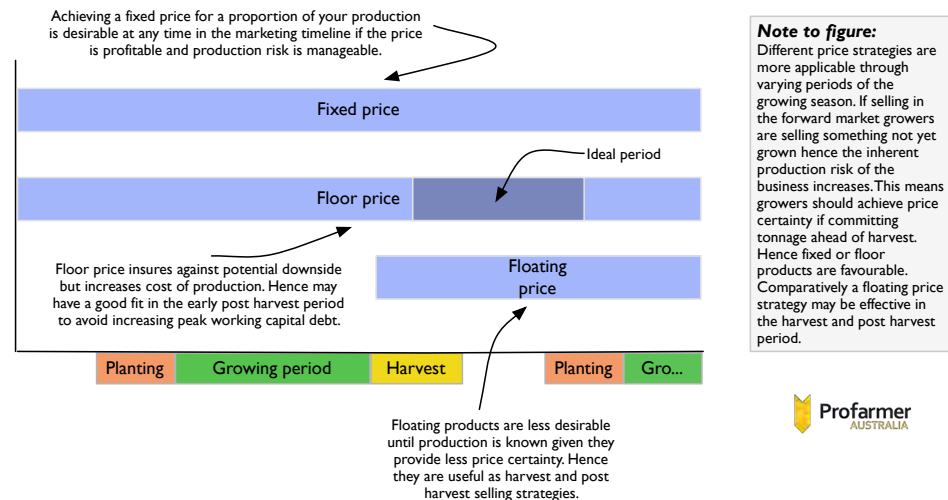


Figure 8: Price strategy timeline through the growing season.

**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.

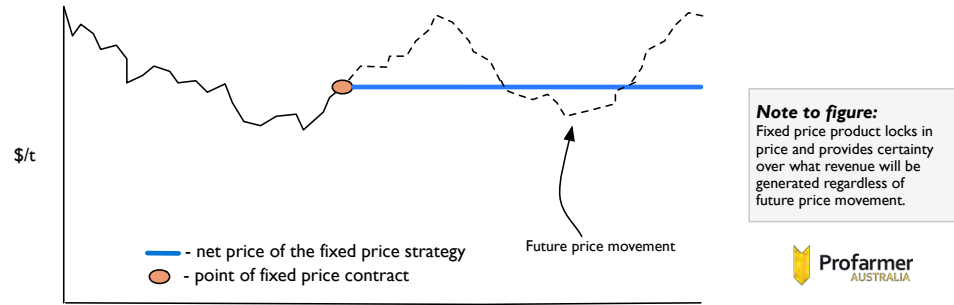


Figure 9: Fixed-price strategy.

**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 business cost of production.

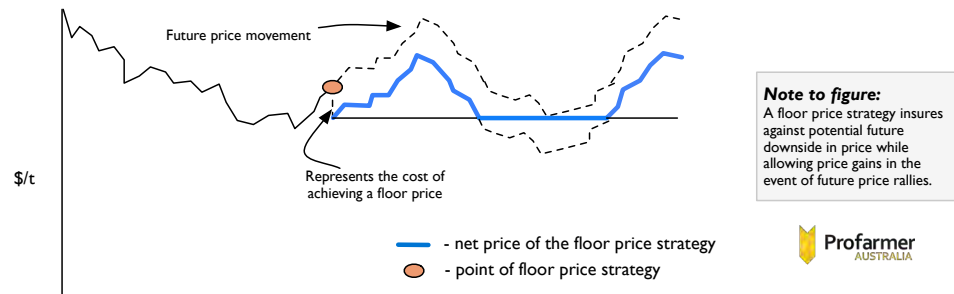


Figure 10: Floor-price strategy.

**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.

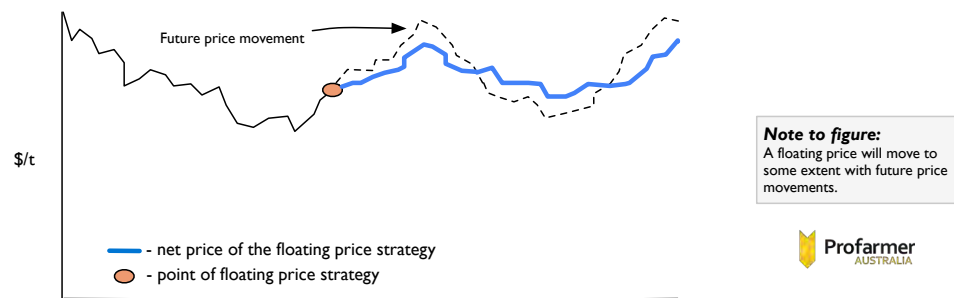


Figure 11: Floating-price strategy.

**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 certainty; 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).

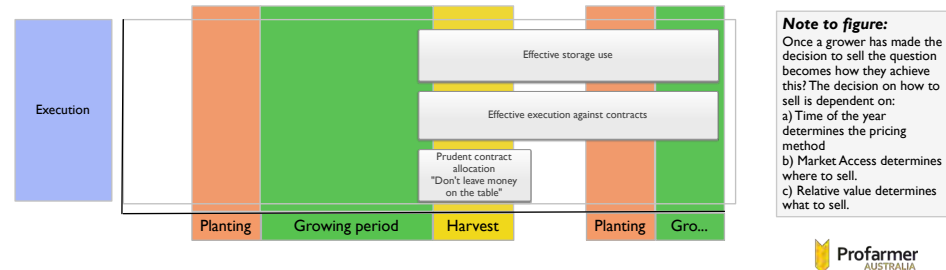


Figure 12: Effective storage decisions.

#### 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. Hence, 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.

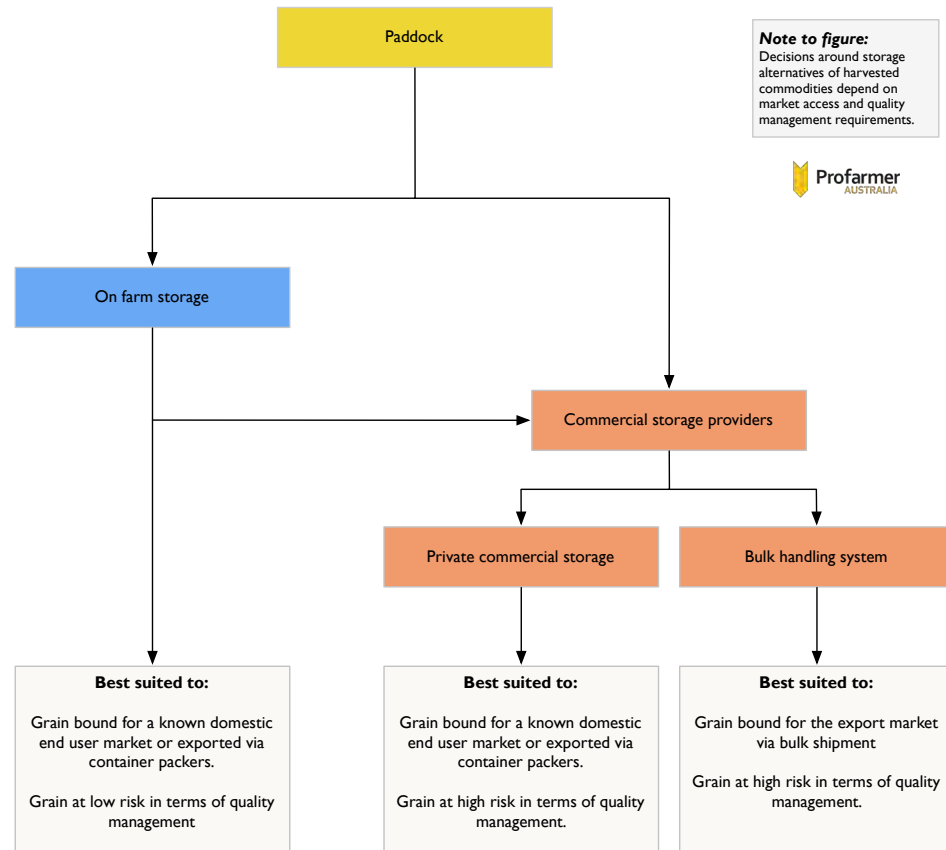


Figure 13: Grain storage decision-making.

For more information about on-farm storage alternatives and economics, refer to [GrowNotes Wheat Southern Region. Section 13. 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); and
- 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 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 (Figure 14).

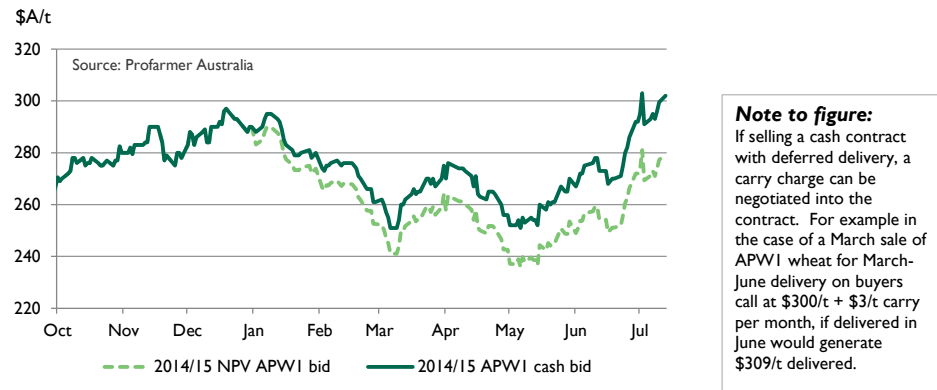


Figure 14: Port Adelaide Australian Premium White 1 (APW1) wheat cash v. net present value (NPV).

### 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 tool box

Selling opportunities can be captured when they arise by assembling the necessary tools in advance. The toolbox includes:

1. Timely information. This is critical for awareness of selling opportunities and includes: market information provided by independent parties; effective price discovery including indicative bids, firm bids, and trade prices; and other market information pertinent to the particular commodity.
2. 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 relationship. 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.
3. 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; hence, devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.

- **Quantity and quality.** When entering a cash contract, you are committing to delivery of the nominated amount of grain at the quality specified. Therefore, 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.

**GTA Contract No.3  
CONTRACT CONFIRMATION**  
GTA Trade Rules and Dispute Resolution Rules apply to this contract

This Contract is confirmation between:

**BUYER**  
Contract No:  
Name:  
Company:  
Address:  
Buyer ABN:  
NGR No:

**SELLER**  
Contract No:  
Name:  
Company:  
Address:  
Seller ABN:  
NGR No:

The Buyer and Seller agree to transact this Contract subject to the following Terms and Conditions:

Commodity: \_\_\_\_\_  
Grade: \_\_\_\_\_  
Quantity: \_\_\_\_\_  
Packaging: \_\_\_\_\_  
Price: \_\_\_\_\_  
Price Basis: \_\_\_\_\_  
Delivery/shipment Period: \_\_\_\_\_  
Delivery Point and Conveyance: \_\_\_\_\_  
Payment Terms: The buyer agrees to pay the seller within \_\_\_\_\_ In the absence of a declaration, payment will be 30 days end of week of delivery.

Levies and charges: Any industry, statutory or government levies which are not included in the price of the commodity as required by law.

Disclosures: Is any of the crop referred to in this contract subject to a mortgage, Encumbrance or lien and/or Plant Breeder's Rights and/or EPR liabilities and/or registered or unregistered Security Interest?  NO  YES (Please provide appropriate details)

Other Special Terms and Conditions:

All Contract Terms and Conditions as set out above and on the reverse of this page form part of this Contract. Terms and Conditions written on the face of this Contract Confirmation shall overrule all printed Terms and Conditions on the reverse with which they conflict to the extent of the inconsistency. This Contract comprises the entire agreement between Buyer and Seller with respect to the subject matter of this Contract.

Recipient Created Tax Invoice (RCTI). To assist with the processing of the Goods and Services Tax compliance, the buyer may prepare, for the seller, a Recipient Created Tax Invoice (RCTI). If the seller requires this service they are required to sign this authorisation.  
 Please issue a RCTI (Please )

Incorporation of GTA Trade & Dispute Resolution Rules: This contract expressly incorporates the GTA Trade Rules in force at the time of this contract and Dispute Resolution Rules in force at the commencement of the arbitration, under which any dispute, controversy or claim arising out of, relating to or in connection with this contract, including any question regarding its existence, validity or termination, shall be resolved by arbitration.

Buyer's Name: \_\_\_\_\_  
Buyer's Signature: \_\_\_\_\_  
Date: \_\_\_\_\_

Seller's Name: \_\_\_\_\_  
Seller's Signature: \_\_\_\_\_  
Date: \_\_\_\_\_

This Contract has been executed and this form serves as confirmation and should be signed and a copy returned to the buyer/seller immediately. 2014 Edition  
©GTA. For GTA member use only.

Grain Trade Australia is the industry body ensuring the efficient facilitation of commercial activities across the grain supply chain. This includes contract trade and dispute resolution rules. All wheat contracts in Australia should refer to GTA trade and dispute resolution rules.

Figure 15: Typical cash contracting as per Grain Trade Australia standards.

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. Figure 16 shows 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.

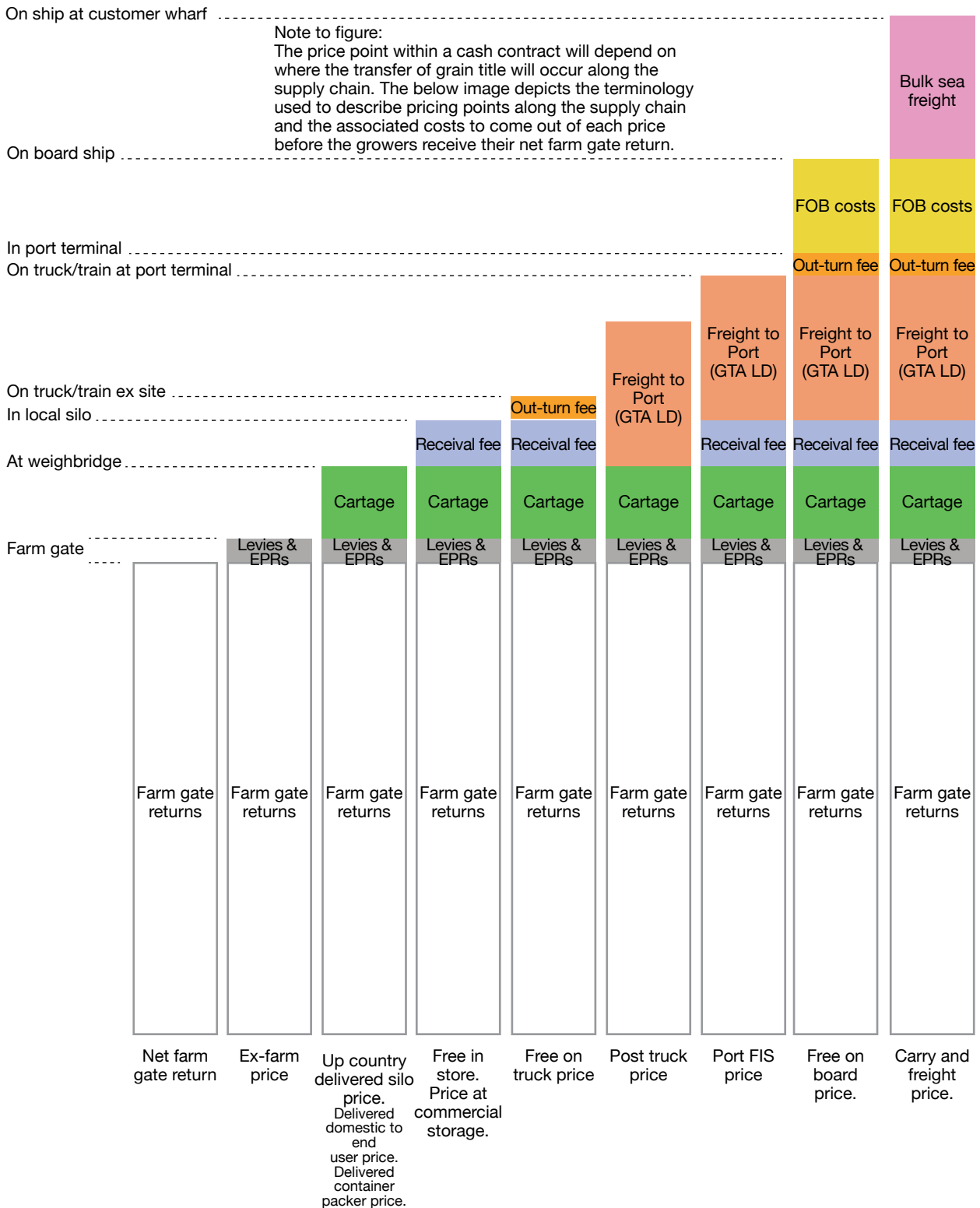


Figure 16: Costs and pricing points throughout the supply chain.

## More information

[GTA Guide to taking out contracts](#)

[GTA Contracts and vendor declarations](#)

[GTA Trading standards](#)

[GrainTransact Resource Centre](#)

[GrainFlow Network](#)

[Emerald Grain customer and grower logins](#)

[Clear Grain Exchange terms and conditions](#)

[Clear Grain Exchange—getting started](#)

Cash sales generally occur through three methods:

1. **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.
3. **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 get payment.

Counterparty risk management includes the following principles:

- 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.

## More information

[GTA Grain contracts—managing counterparty risk](#)

[Clear Grain Exchange title transfer model](#)

[GrainGrowers Guide to managing contract risk](#)

[Counterparty risk management: A producer perspective—Leo Delahunty](#)



**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.

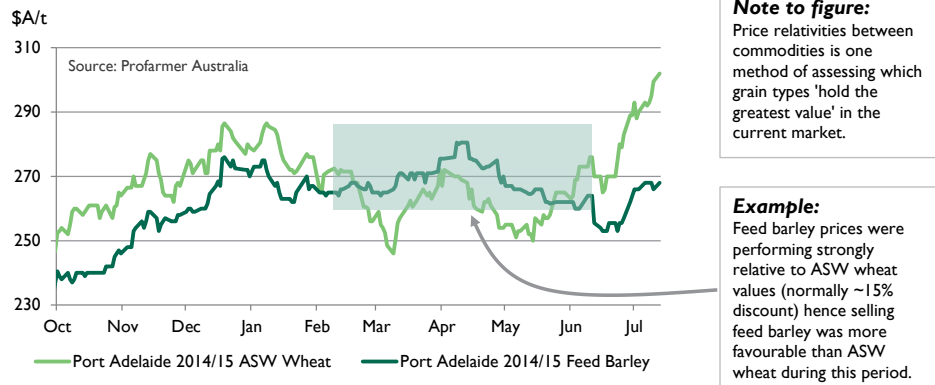


Figure 17: Port Adelaide Australian Standard White (ASW) wheat v. feed barley (AU\$/t).

If the decision has been made to sell wheat, CBOT wheat may be the better alternative if the futures market is showing better value than the cash market (Figure 18).

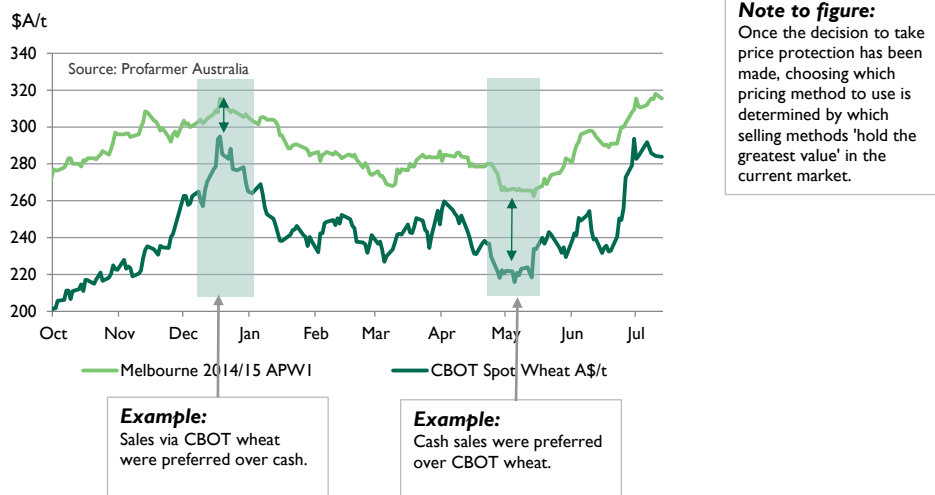


Figure 18: 2014–15 Melbourne Australian Premium White 1 (APW1) wheat v. Chicago Board of Trade (CBOT) wheat (AU\$/t).

### 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, oil bonuses, etc.), and optimising your allocation reflects immediately on your bottom line (Figure 19).

**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 wheat price, growers should allocate:

- lower grades of wheat to contracts with the lowest discounts; and
- higher grades of wheat to contracts with the highest premiums.

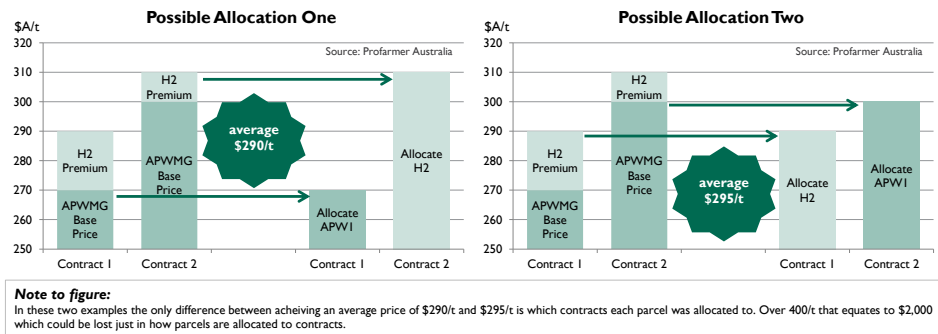


Figure 19: Examples of contract allocation of grain.

### 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:

1. 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 cash prices are susceptible to falling \$5/t if that buyer satisfies their buying appetite.
2. 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.

### Summary

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 wheat—market dynamics and execution

### 15.2.1 Price determinants for southern wheat

Australia is a relatively small player in terms of world grain production, with ~3.5% of global wheat production. However, in terms of world trade, Australia is a major player, exporting ~60–75% of the national wheat crop, which accounts for ~15% of global wheat trade.

Given this dynamic, Australian farm-gate prices are heavily influenced by global price volatility. This makes offshore markets such as CBOT useful indicators of where Australian wheat prices will trade.

In South Australia, ~85% of annual production is exported; however, in Victoria the domestic market (including containers) consumes 80–100% of the state’s average annual wheat crop (3.0 Mt). As a result, wheat 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 (Figure 20). Typically, Victoria relies on ‘importing’ up to 1.0 Mt annually from southern NSW.

When southern Australia has a large crop, local wheat values should largely correlate to global prices. Hence, the timing of harvest in major exporting and importing countries is a considerable influence on wheat prices in South Australia, Victoria and southern New South Wales. Figure 21 highlights some of the seasonal factors influencing global wheat prices throughout each year.

Prices can be compared with historic values by consulting decile charts (Figure 22).

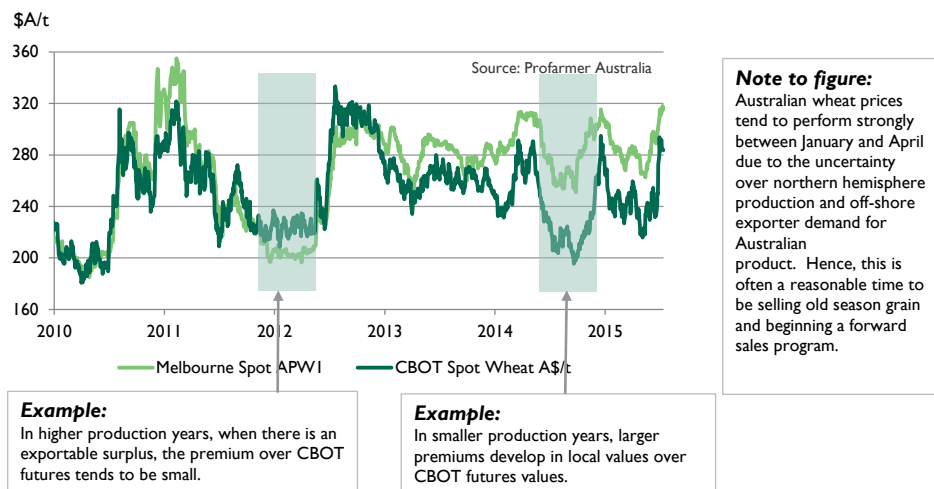


Figure 20: 2010–15 Melbourne Australian Premium White 1 (APW1) wheat v. Chicago Board of Trade (CBOT) wheat (AU\$/t).

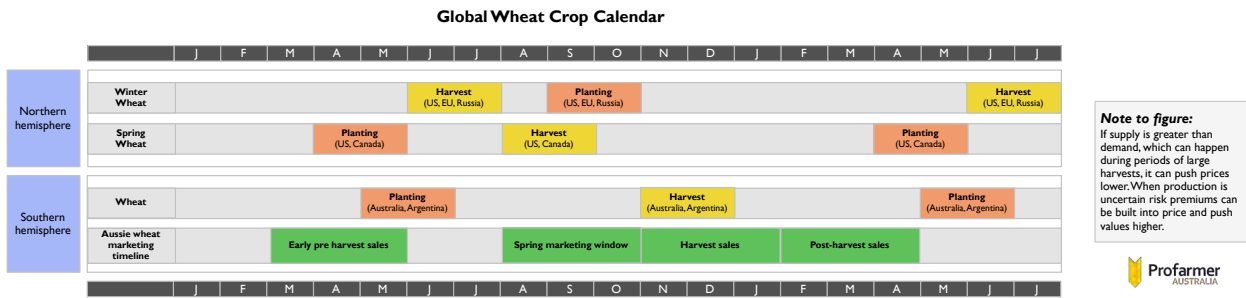


Figure 21: 2010–15 Melbourne Australian Premium White 1 (APW1) wheat v. Chicago Board of Trade (CBOT) wheat (AU\$/t).

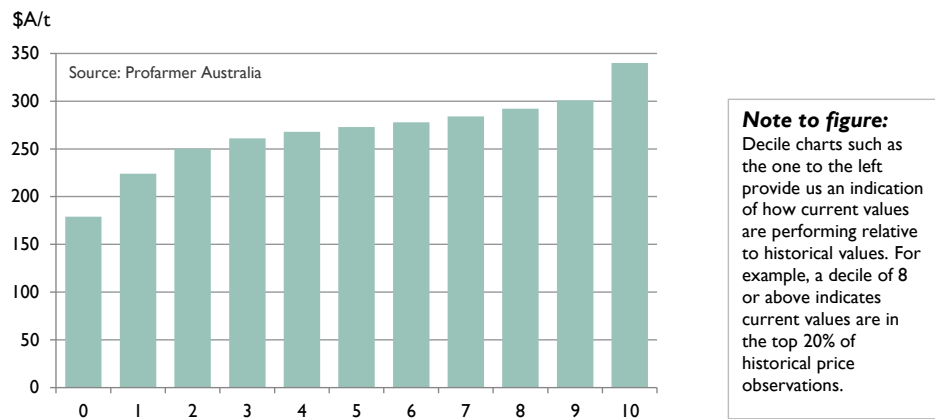


Figure 22: Decile chart illustrating the price distribution for Port Adelaide Australian Premium White 1 (APW1) wheat.

### 15.2.2 Ensuring market access for southern wheat

For wheat grades likely to be exported in bulk for human consumption, a bulk handling system is often the most cost-effective pathway to get grain to offshore customers. The bulk storage provider should gain scale efficiencies when moving the bulk commodity grades such as APW1, ASW1, H<sub>2</sub>, and H1 in seasons when there is a considerable surplus.

South-eastern Australia also has a prominent domestic wheat market that can generate premiums to the bulk export markets and provide a return to on-farm storage for growers well positioned to service this demand. As a result, private commercial and on-farm storage should play a significant role in the storage decisions of Victorian and southern New South Wales wheat growers to access domestic end-user and container markets.

The level of wheat exports in containers from Victoria is regularly >1.0 Mt (Figure 23). The container trade can provide price premiums for specific grades because a container can access niche offshore markets. At times, off-spec grades such as high-protein or high-screenings loads may provide better returns through this channel than through the centralised BHC (bulk handling company) channel where stricter commodity standards may apply.

Supply-chain flow options are illustrated in Figure 24.

	Victoria		South Australia		National Total	
	Implied tonnes	% of production	Implied tonnes	% of production	Implied tonnes	% of production
Bulk	1.9 Mt	52%	4.4 Mt	91%	16.72 Mt	65%
Container	1.5 Mt	41%	0.7 Mt	14%	2.28 Mt	9%
Domestic Use	1.1 Mt	31%	0.1 Mt	2%	6.67 Mt	25%

Source: Australian Crop Forecasters

Figure 23: Market destinations for wheat—southern Australian and national 5-year averages.

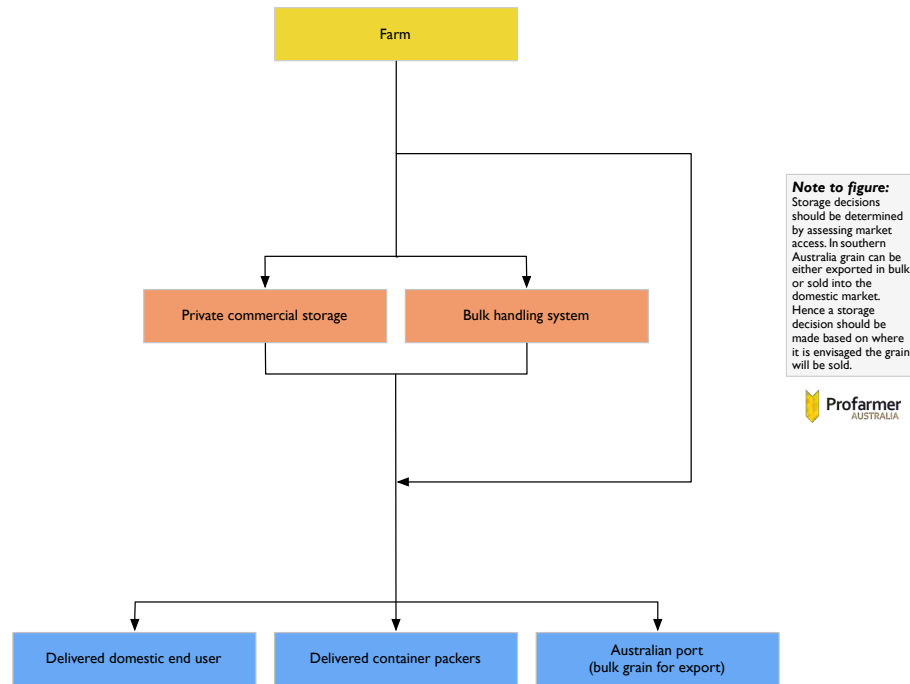


Figure 24: Australian supply-chain flow for wheat.

### 15.2.3 Executing tonnes into cash for southern wheat

Knowing where the wheat 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 at 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 Australian wheat 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 25).

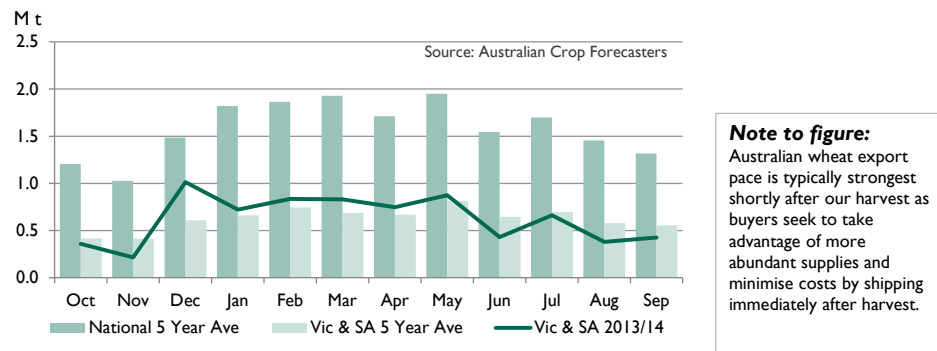


Figure 25: Monthly export pace of wheat.

What does this mean for a southern wheat grower? Demand is generally strongest for wheat during the harvest period, when type A and type B customers are both active in the market; hence, the number of buyers bidding for wheat 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 grades to hold. Some wheat grades, such as high-protein (H1, H<sub>2</sub>), 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 while it is available. This appetite tends to push up the price premium for these grades over base APW1, making them a more attractive harvest sell. These grades are a higher risk to be holding for post-harvest sales, because once the buyers have their requirements covered, prices tend to move toward APW1 levels as buyers begin to drop out of the market (Figure 26).

Lower grades such as ASW1 and AGP1 tend to be more heavily discounted at harvest, with the grade-spread closing up after harvest as many feed users continue to buy on an as-needs basis. This makes such wheat grades a lower risk and more desirable to hold for post-harvest sales.

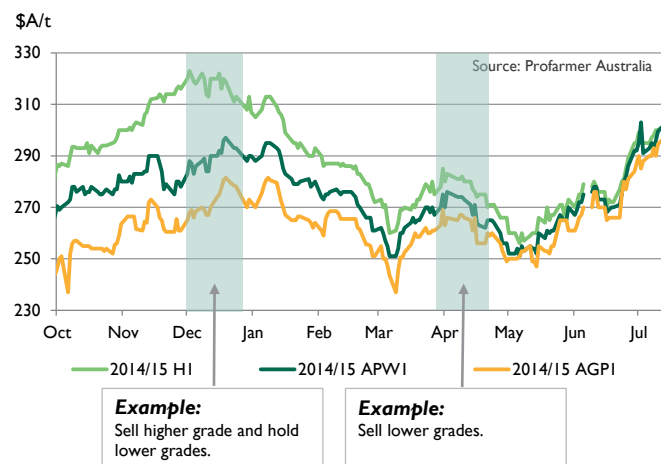


Figure 26: Monthly prices of Port Adelaide Australian Hard 1 (H1) v. Australian Premium White 1 (APW1) v. Australian General Purpose 1 (AGP1) (AU\$/t).

#### 15.2.4 Risk-management tools available for southern wheat

An Australian cash price has three components: futures, foreign exchange, and basis (Figure 27). Each component affects price. A higher futures and basis and a lower exchange rate will create a higher Australian grain price.

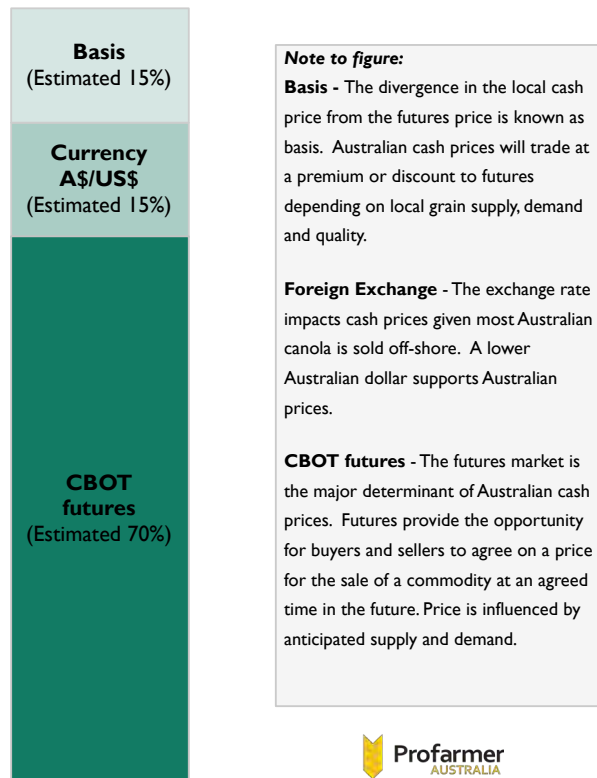


Figure 27: Components of pricing.

Table 2 outlines products available to manage southern Australian wheat prices; the major difference in products is the ability to manage the individual components of price.

Table 2: Advantages and disadvantages of the products available to manage wheat prices

	Description	Advantages	Disadvantages
Spot cash contracts	Futures, foreign exchange, basis all locked at time of contracting	<ul style="list-style-type: none"> <li>Simple to use.</li> <li>Locks in all components of price.</li> <li>Cash is received almost immediately (within payment terms).</li> </ul>	<ul style="list-style-type: none"> <li>Immediate grain delivery required.</li> <li>Sales after harvest require storage which incur costs.</li> <li>Locks away three pricing components at the same time.</li> <li>Risk of counterparty default between transfer and payment.</li> </ul>
Forward cash contracts	Futures, foreign exchange, basis all locked at time of contracting	<ul style="list-style-type: none"> <li>Simple to use.</li> <li>Locks in all components of price (no uncovered price risk).</li> <li>No storage costs.</li> <li>Cash income is a known ahead of harvest</li> </ul>	<ul style="list-style-type: none"> <li>Often inflexible and difficult to exit.</li> <li>Locks away the three pricing components at the same time.</li> <li>Future delivery is required resulting in production risk.</li> <li>Counterparty default risk must be managed.</li> </ul>
Futures contracts	Futures, foreign exchange, basis are able to be managed individually	<ul style="list-style-type: none"> <li>Liquid markets enable easy entry and exit from the marketplace.</li> <li>Locks in only some components of price, hence more flexible than cash contracts.</li> <li>Price determined by the market, and is completely transparent.</li> <li>No counterparty risk due to daily clearing of the contracts.</li> </ul>	<ul style="list-style-type: none"> <li>Requires constant management and monitoring.</li> <li>Margin calls occur with market movements creating cash-flow implications.</li> <li>Grain is required to offset the futures position, hence production risk exists.</li> <li>Cash prices may not move in line with futures, hence some price risk.</li> <li>You still have to sell the underlying physical grain.</li> </ul>
Over-the-counter bank swaps on futures contracts	Futures, foreign exchange, basis are able to be managed individually	<ul style="list-style-type: none"> <li>Based off an underlying futures market so reasonable price transparency.</li> <li>Liquid markets enable easy entry and exit from the marketplace.</li> <li>Locks in only some components of price, hence more flexible than cash contracts.</li> <li>Counter party risk is with the bank, hence it is low.</li> <li>The bank will manage some of the complexity on behalf of the grower, including day to day margin calls.</li> </ul>	<ul style="list-style-type: none"> <li>Costs vary between \$5-10/t at the providers discretion.</li> <li>Requires constant management and monitoring.</li> <li>Grain is required to offset the futures position, hence production risk exists.</li> <li>Cash prices may not move in line with futures, hence some price risk.</li> <li>You still have to sell the underlying physical grain.</li> </ul>
Options on futures contracts	Futures, foreign exchange, basis are able to be managed individually	<ul style="list-style-type: none"> <li>No counterparty risk due to daily clearing of the contracts.</li> <li>No margin calls.</li> <li>Protects against negative price moves but can provide some exposure to positive moves if they eventuate.</li> <li>Liquid markets enable easy entry and exit from the marketplace.</li> <li>Price risk can be reduced without increasing production risk.</li> <li>Price determined by the market, and is completely transparent.</li> </ul>	<ul style="list-style-type: none"> <li>Options can be costly and require payment upfront.</li> <li>The value of options erode overtime as expiry approaches - depreciating asset.</li> <li>Perceived to be complicated by growers.</li> <li>Move in option value may not completely offset move in cash markets.</li> <li>You still have to sell the underlying physical grain.</li> </ul>

For more information and worked examples on how each pricing component affects wheat grain price, refer to the GRDC publication: [Grain Market Lingo—what does it all mean?](#)



## SECTION 16

# Current research

## Project Summaries of GRDC-supported 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](mailto:feedback@grdc.com.au)



## 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](mailto: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](mailto:michael.mclaughlin@adelaide.edu.au) or

[mike.mclaughlin@csiro.au](mailto: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 mixed-farming 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](mailto:john.bennett5@bigpond.com)



## 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](mailto: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.

M 0417 803 034

E [bill@agconsulting.com.au](mailto: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](mailto: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.

M 0429 701 170

E [rohanmott@gmail.com](mailto:rohanmott@gmail.com)



## 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](mailto: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](mailto: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](mailto:kate.wilson@agrivision.net.au)



## Tanya Howitt

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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](mailto:tanya.howitt@grdc.com.au)



## Rebecca Jeisman (Panel support)

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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 [rebecca@agcommunicators.com.au](mailto:rebecca@agcommunicators.com.au)



## SECTION 18

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