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SOUTHERN
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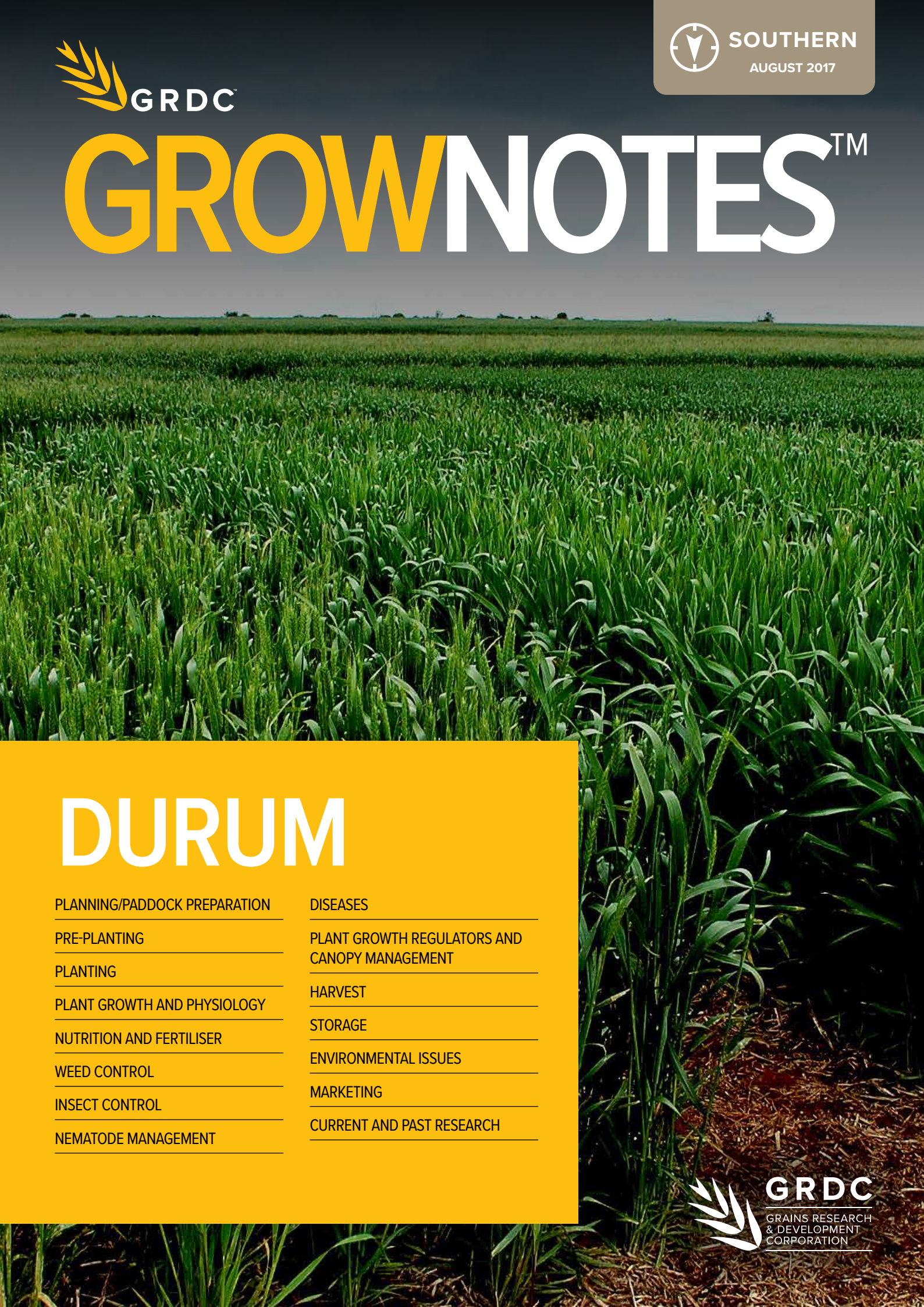

DURUM

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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Start here for answers to your immediate durum crop management issues

What are the advantages of growing a durum crop?

What can I do to avoid crown rot infection in durum?

How do I ensure that durum reaches 13% protein standard?

What are the important weed control strategies for durum?

Is durum a break crop for nematodes?

Keys to successful durum production

NO SOWING

Do not sow durum into paddocks with crown rot

Lower seeding rates can leave durum at risk of being overrun with **RYEGRASS**

Durum can perform well when sown later, but make sure to consult your agronomist

Saline conditions can limit durum growth

High nitrogen is essential to ensure durum reaches its minimum protein level of 13%

12.5%

Harvest durum at 12.5% moisture

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5 Nutrition and fertiliser

6 Weed control

8 Nematode management

14 Environmental issues

Introduction

Key messages:

- Premium durum grain is known for its hardness, protein, intense yellow colour, nutty flavour and excellent cooking qualities.
- It has vitreous, amber-coloured kernels with a minimum protein of 13%.
- Durum wheat differs from the other wheats in having endosperm that does not break into fine flour when milled but into coarse semolina, ideal for pasta making.
- In south-eastern Australia durum is grown primarily under rain fed conditions (sown in May–June) characterised by dry, hot summers alternating with humid and temperate winters (harvested in November–December). [1]

A.3 Crop overview

Durum wheat (Photo 1; *Triticum turgidum* L. subsp. *durum* Desf. Husn.) or pasta wheat is an important crop for the human diet and is known for its hardness, protein, intense yellow colour, nutty flavour and excellent cooking qualities. [2] In Australia, durum production averages ~400,000 tonnes (t) but has fluctuated substantially between ~50,000 and 800,000 t over the period 1995–2008. [3] In 2005–06, production was ~450,000 t, with New South Wales (NSW) accounting for around 67% and South Australia (SA) around 26% of current production (Table 2). The balance is produced in Queensland, Victoria and. Western Australia (WA). [4]

FAQ

Australian durum (ADR1) consists of selected wheat varieties with vitreous, amber-coloured kernels with a minimum protein of 13%. Durum wheat differs from the other wheats in having endosperm that does not break into fine flour when milled but into coarse semolina, ideal for pasta making. The free-milling grain is capable of achieving high yields of superior quality semolina with minimal residual flour production. The semolina produced from this specialised wheat exhibits high levels of stable yellow pigment and high water absorption, making it ideally suited to the production of a wide range of high quality wet and dry pasta products with excellent colour and shelf life. Durum is produced primarily in SA, northern NSW, Queensland and areas where hard and prime hard wheat are grown. There is growing production within the Wimmera district of Victoria. Tonnages produced are sufficient to satisfy domestic requirements and, increasingly, international market demands. [5]

1 M Sissons, B Ovenden, D Adorada, A Milgate (2014) Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411-422

2 M Sissons (2004) Pasta. In Encyclopedia of grain science. (Eds C Wrigley, H Corke, C Walker), Elsevier Academic Press: London

3 R Ranieri, G Worden, ML Seghezzo, C Mills (2012) Marketing perspectives in the durum wheat trade. In Durum wheat chemistry and technology, 2nd edn (Eds M Sissons, J Abecassis, B Marchylo, M Carcea) AACC International: Saint Paul, Minnesota, USA

4 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

5 AWB (2014) Australian wheat. Australia Wheat Board, http://www.awb.com.au/customers/australianwheat/

Photo 1: *Durum wheat.*

Photo: Rachel Bowman

Over the last few years, increasing emphasis has been placed on supplying wheat of specific qualities as flour milling and processing industries overseas have become more sophisticated. Current markets require wheat grades in which there is a balance between grain hardness and protein content for different end uses. Figure 1 shows the relevant protein hardness values and the different end uses for each grade of wheat.

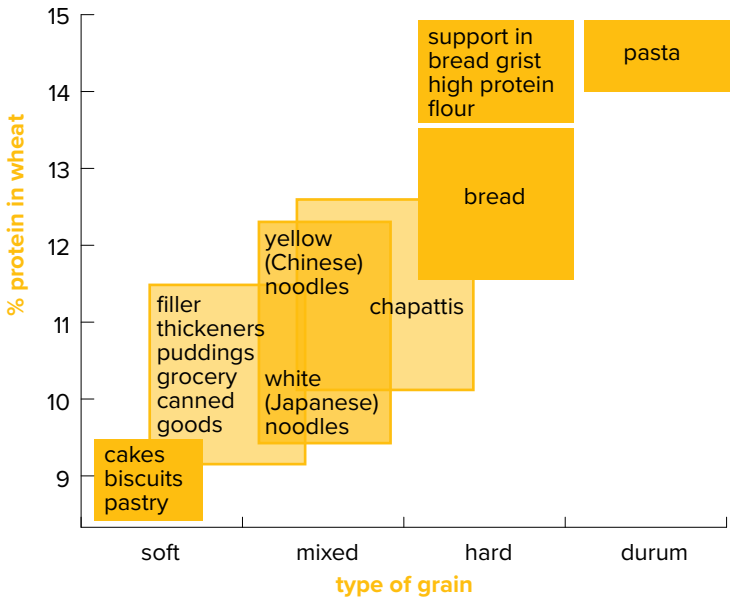

Figure 1: *Balance between protein content, hardness and end-product requirements.*

Source: Weston Milling

Durum wheat should only be grown on highly fertile soils where high protein grain can be produced, as protein levels >13% are required to meet premium market grades. Protein levels below 10% can be marketed only as feed, although grain

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WATCH: GCTV8: Durum in demand.

with a protein between 10-13% can still be marketed as lower grade durum. [6] In south- eastern Australia durum is grown primarily under rain fed conditions (sown in May–June) characterised by dry, hot summers alternating with humid and temperate winters (harvested in November–December). [7]

New breeding material has shown promise in the lower rainfall areas with yields similar to bread wheat varieties in average seasons. Durum varieties tend to be more sensitive to low levels of zinc and trials have given large yield increases with the application of zinc where zinc was limiting. In areas where high protein wheat can consistently be produced, newer durum varieties may be a profitable option, especially when there is a large price differential between durum and hard wheat. [8]

On receival at a mill, durum grains are cleaned to remove chaff and foreign material. Grain is then milled to remove the bran and germ. The remaining endosperm is cracked into coarse pieces and then ground very, very finely into semolina for pasta making. ADR1 yields high levels of top quality gluten, associated with high grain protein. This means the pasta dough has good stretch, texture and durability and is able to hold its shape when cooked. [9]

A.4 Growing regions

The southern durum growing region stretches from Victoria, Tasmania and South Australia and the south-west corner of Western Australia. The rainfall pattern ranges from uniform in central New South Wales through to winter-dominant in Victoria, Tasmania, South Australia and Western Australia.

This is a vast region of the country, with a typically Mediterranean climate of dry summers and comparatively reliable winter rainfall lending itself to winter crop production.

Planting of the winter crop depends on “opening rains” and usually begins in May and can continue through until late July. The winter crop harvest can begin in late October and continue through until January in the higher rainfall areas. [10]

Durum is grown through Victoria, Tasmania and SA (Table 1) up to central NSW (south of Dubbo) and through the south-west corner of WA. Rainfall patterns range from winter-dominant in Victoria, Tasmania, SA and WA through to uniform in central NSW.

6 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

7 M Sissons, B Ovenden, D Adorada, A Milgate (2014) Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411-422

8 PIRSA. http://pir.sa.gov.au/__data/assets/word_doc/0005/241583/Impact_of_dry_sow,_frost,_crop_type_and_variety.doc

9 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

10 AEGIC (2016) Australian grain production—a snapshot, http://aegic.org.au/australian-grain-production-a-snapshot/

Table 1: *Crop estimates by district in South Australian growing regions. South Australia's area of Durum production in 2016/2017. Greatest production was centred in Upper South East, Yorke Peninsula, Upper North and Mid North districts.*

		Western Eyre Peninsula	Lower Eyre Peninsula	Eastern Eyre Peninsula	Yorke Peninsula	Upper North	Mid North	Lower North	Kangaroo Island
Wheat	ha	477 000	145 000	392 000	165 000	236 000	234 000	56 500	5 700
	t	955 000	553 000	1 019 000	676 000	637 000	936 000	243 000	12 500
Durum	ha	0	0	0	20 000	9 500	8 500	6 500	0
	t	0	0	0	71 000	26 500	33 500	25 000	0
		Central Hills & Fleurieu	**Lower Murray**	**Nth Murray Mallee**	**Sth Murray Mallee**	**Upper South East**	**Lower South East**	**State Total**	
Wheat	ha	4 500	66 000	245 000	124 000	65 000	22 000	2 237 700	
	t	11 000	164 000	490 000	322 000	188 000	70 000	6 276 500	
Durum	ha	300	600	300	0	9 500	0	55 200	
	t	650	1 300	500	0	24 000	0	182 450	

Source: Primary Industries and Regions SA

A.5 Brief history

Durum wheat was first produced in Australia in the early 1930s. Due to a combination of strong international prices, very high quality grain and improved export marketing facilities, Australian durum wheat production has made impressive growth from around 8,000 tonnes produced in northern NSW and SA in the late 1970s to current domestic production of around 500,000 tonnes. [11]

The Australian durum wheat industry is highly competitive with the leading overseas producers (i.e. Canada, the United States, the European Union, Turkey and Syria). Australian durum quality is now regarded by Italian millers and producers as the best in the world.

Table 2: *Historical durum wheat production in Australia, 1994–2007 (tonnes by State).*

Season	Queensland	NSW	Victoria	SA	WA	Total production (tonnes)
1994–95	2,000	2,000	0	33,000	0	37,000
1995–96	6,000	55,000	0	65,000	1,000	127,000
1996–97	5,997	210,000	0	51,000	0	266,997
1997–98	4,971	200,600	0	82,601	0	288,172
1998–99	10,737	303,730	0	84,429	984	399,880
1999–00	51,382	527,358	0	142,423	5,120	726,283
2000–01	6,334	138,696	0	269,524	4,009	418,830
2001–02	6,033	380,696	0	405,565	4,142	796,283
2002–03	8,100	55,000	0	162,000	3,000	228,100
2003–04	47,700	337,000	2,000	217,900	6,895	611,495
2004–05	50,000	375,000	2,000	220,000	7,000	654,000
2005–06	16,230	297,135	6,500	117,086	5,200	442,151

11 DPI NSW. (2016). Durum wheat production. http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/durum-wheat-production

Season	Queensland	NSW	Victoria	SA	WA	Total production (tonnes)
2006–07	10,000	125,000	10,000	50,000	5,000	200,000
5-year average	26,406	237,827	5,125	153,397	5,419	427,149

Source: NSW Department of Primary Industries

Durum from southern Australia is also used in Coopers home brew kits which are shipped around the globe. [12]

The San Remo pasta manufacturer, in Adelaide, is the largest Australian user of durum at approximately 100,000 t annually (2008 data). This is forecast to rise to 200,000 t by 2023. The other major user is the food manufacturer Rinoldi, in Melbourne. [13]

A.6 Economics of durum production

When grown using best production practices and under optimal conditions, durum can produce higher profits than bread wheat (Table 3). [14] GRDC has worked with the South Australian Grain Industry Trust (SAGIT) and the Government of South Australia to develop a *Farm Gross Margin and Enterprise Planning Guide* which includes durum.

Table 3: *Summary of calculations for gross margins in the 2016 bread wheat and durum wheat trials conducted as part of UA415 sponsored through SAGIT.*

Bread / durum gross margin analysis							2016
		Low Yield Low Price	Low Yield High Price	High Yield Low Price	High Yield High Price	Average GM	Actual Best GM
Coonalpyn	Bread	702	862	802	980	817	912
	Durum	1462	1737	1816	2146	1834	2035
Roseworthy	Bread	686	823	1095	1290	929	1095
	Durum	1697	1697	2176	2176	2019	2176
Sanderston	Bread	819	961	892	1044	947	1044
	Durum	258	1246	294	1357	1060	1357
Wandereah	Bread	380	475	562	684	539	684
	Durum	1164	1164	1385	1385	1284	1385
Yeelanna	Bread	359	629	548	898	655	790
	Durum	303	1067	353	1191	711	1067

Notes: The calculations for these gross margin figures can be found in the supporting documents. When assessing the gross margins the following points should be noted:

1. Input prices are as charged to the durum breeding group, and are in general higher than a farmer would pay due to product size.
2. Delivery charges and rail freight are to the nearest silo, and have been taken from either Viterra or AWB websites.
3. It is assumed all durum would be delivered to Balaklava, unless it only made feed quality in which case it would go to the nearest silo.
4. If screenings was the only limiting factor to a higher grade being paid, a cost of $14 per tonne was deducted and the yield lowered to the amount it would be with 5% screenings. No value was placed on screenings. This makes the assumption that the protein will not drop with the removal of screenings.
5. These calculations do not consider a carry-over price or put a value on the need to store grain on farm, it only looks at a hectare of crop in the field.
6. At Sanderston, the farmer applied a protective application of rust control which was applied to both bread and durum. The durum did not need this spray and it has not been included in the cost of production.
7. The high, low, and average refer to the 4 durum and 4 bread wheat varieties grown in these trials.

12 PIRSA (2016) South Australia food and wine: key messages and fast facts, April 2016, http://pir.sa.gov.au/__data/assets/pdf_file/0020/271208/SA_Food_and_Wine_Key_Messages_Fast_Facts.pdf

13 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

14 SAGIT. (2016). Growing durum demand in SA: gross margin sensitivity analysis trials. http://durumgrowerssa.org.au/wp-content/uploads/2017/02/UA415-Supplementary-File-1_2016.pdf

Planning/Paddock preparation

Key messages:

- Durum should be grown in fertile paddocks, preferably with good stored moisture.
- Avoid sowing into paddocks with high pre-existing levels of crown rot fungus (*Fusarium pseudograminearum*).
- Crop rotations using pulses, canola, sorghum, sunflowers and pasture legumes are recommended to help disease and weed control. Legume break crops are ideal due to their ability to fix substantial amounts of nitrogen.
- Limited and strategically timed tillage could help control weeds and disease in minimum tillage systems.
- High nitrogen is essential to maximise the potential of durum to reach its minimum protein level of 13%.
- Testing paddocks for and controlling disease, nematodes and insects is essential to manage risks and maximise yield.

1.1 Paddock selection

Durum should not be grown in paddocks at high risk of grass weed competition.

Choice of paddock to sow cereals is 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. [1]

Successful crop establishment is the key to maximising crop yield potential. Focus on paddock selection, the use of good quality seed, optimising seeding rate, depth and spacing, and matching varieties to seeding date and length of growing season.

Durum wheat grows best on soils with good water holding capacity (generally clay and clay-loams). [2] Select paddocks that are fertile and store good levels of plant available water, receive reliable in-crop rainfall or have access to supplementary irrigation. Durum wheat should only be grown where a reliable harvest of high protein (13%+), plump, hard, vitreous grain can be produced. The highest grade of durum (ADR1) must have a minimum protein level of 13% and ADR2 must be at least 11.5%. Careful management of soil nitrogen (N) is essential to achieve this (Photo 1). [3]

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

2 A Mayfield, H van Rees (1994) Durum wheat. In The Southern Mallee and Northern Wimmera Crop and Pasture Manual, http://www.farmtrials.com.au/trial/13301

3 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

Photo 1: *Trials run over several years and sites highlight that the newer durum lines, such as Saintly(D (pictured) do not require extra nitrogen for growth but require more nitrogen to achieve 13% protein. (Source: DAFQ)*

Photo: Emma Leonard, Source: GRDC

Durum wheats should not be sown into paddocks known to carry high levels of crown rot inoculum. A suitable rotation should be practiced to reduce inoculum levels. Ground preparation is the same as that for bread wheat. Adequate weed control should eliminate all weeds and volunteer plants of bread wheat, barley or other crop species. [4]

Paddock topography

Topographical characteristics can determine crop and pasture options. Crops and varieties prone to lodging should be avoided in uneven paddocks. Some durum varieties such as Saintly can be prone to lodging, so topography is an important factor in paddock selection (Photo 2). Waterlogged conditions make harvest difficult and also reduce root growth and can predispose the plant to root rots. The topographic variations typical of large agricultural paddocks can have a substantial impact on dynamics of soil mineral N as well as on performance of crops. Spatial variations in soil organic matter, soil microbial biomass, natural drainage, plant growth, and water and nutrient redistribution caused by topography are the main factors controlling the dynamics of soil mineral N. Along with weather, landscape topographic patterns accounted for most of the variations in plant available N.

There are potential environmental and economic benefits of site-specific topography-driven crop management. Management decisions regarding where to plant crops can vary depending on the management goals and complexity of the terrain. [5]

4 DAFQ (2012) Durum wheat in Queensland. Department of Agriculture and Fisheries Queensland, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

5 Ladoni, M., Kravchenko, A. N., & Robertson, G. P. (2015). Topography Mediates the Influence of Cover Crops on Soil Nitrate Levels in Row Crop Agricultural Systems. *PloS one*, *10*(11), e0143358.

Photo 2: *Topography is an important consideration in paddock selection for durum.*

Photo: Arthur Mostead, Source: GRDC

1.1.1 Soil

Soil pH

Optimum soil pH for durum wheat growth is between 5.5 and 7.5. [6] Soils with low pH often have high levels of aluminium in the soil solution. Durum wheat, is reportedly more sensitive to aluminum (Al) toxicity in acid soils than hexaploid wheat, *Triticum aestivum* L. [7]

- Soil pH is a measure of the concentration of hydrogen ions in the soil solution.
- Low pH values (< 5.5) indicate acidic soils and high pH values (> 8.0) indicate alkaline soils.
- Soil pH between 5.5 and 8 is not usually a constraint to crop or pasture production.
- In Southern Australia more than 60% of agricultural soils are alkaline.
- Outside of the optimal soil pH range, microelement toxicity and deficiency damages crops.

Hydrogen ion concentration in the soil is called pH and is influenced by chemical reactions between soil components and water. Soil pH is affected by the varied combinations of positively charged ions (sodium, potassium, magnesium, calcium, aluminum, manganese and iron) and negatively charged ions (sulfate, chloride, bicarbonate and carbonate). Soil pH directly affects the concentration of major nutrients and the forms of microelements available for plant uptake and can result in deficiencies or toxicities (Figure 1).

6 Brink, M., & Belay, G. (2006). Cereals and pulses. PROTA, Wageningen, Pays Bas

7 Foy, C. D. (1996). Tolerance of durum wheat lines to an acid, aluminum- toxic subsoil. *Journal of plant nutrition*, *19*(10-11), 1381-1394

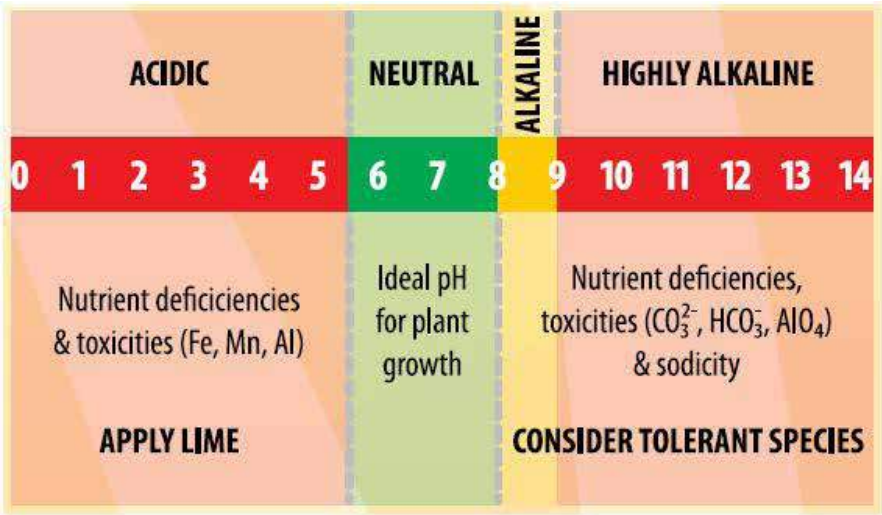

Figure 1: *Effect of soil pH(1:5 soil:water) availability, plant growth and management options. Classification of soils on the basis of pH (1:5 soil:water) the implications for plant growth and some management options.*

Source: Soilquality.org)[8]

What influences location of acid and alkaline soils in southern Australia?

Alkaline soils are found in arid/semi-arid regions, because little leaching and high evaporation causes ions to concentrate in the soil.

Acid soils occur in areas of southern Australia with high rainfall where basic ions (sodium, potassium, magnesium and calcium) have been removed by leaching. Nitrate leaching also contributes to significant soil acidification under high rainfall. Very frequent legume cropping can reduce pH in non-calcareous soils. Soils high in sulfur may become very acidic due to the dominance of certain chemical (oxidation-reduction) reactions.

Measurement of soil pH

Soil sampling and measurement of pH helps to determine the practices necessary to manage land with low or high pH. Sampling strategies need to take into account the variation across a paddock and down the soil profile (see section below).

Soil pH can be measured by a simple device called an ion electrode inserted into a mixture of one part soil to five parts water. Scientists dealing with acid soils with pH less than 5 prefer to measure soil pH using soil in calcium chloride solution. This is not suitable for soils with a pH greater than 5 because some of the ions in these soils (mainly bicarbonate and carbonate) become bound to the calcium and are removed from solution, which then causes an inaccurate pH reading. Soils with pH greater than 5 should be measured in water.

Managing soil pH

Alkaline soils

Treating alkaline soils through the addition of acidifying agents is not generally a feasible option due to the large buffering capacity of soils and uneconomic amounts of acidifying agent (e.g. sulfuric acid, elemental sulfur or pyrites) required.

Gypsum will reduce sodicity and this can reduce alkaline pH to some extent. Growing legumes in crop rotation may help in sustaining any pH reduction.

In high pH soils, using alkalinity tolerant species/varieties of crops and pasture can reduce the impact of high pH.

8 Soilquality.org. Soil pH—South Australia, http://www.soilquality.org.au/factsheets/soil-ph-south-australia

Acid soils

Acid soils can be economically managed by the addition of agricultural lime, usually crushed limestone. Sufficient lime should be added to raise the pH to above 5.5. The amount of lime required to ameliorate acid soils will vary, mainly depending on the quality of the lime, soil type and how acidic the soil has become.

Soils prone to becoming acidic will need liming every few years. Seek advice on an appropriate liming regime from your local agricultural advisor. [9]

Liming

The signs of soil acidity are more subtle than the clearly visible symptoms of salinity and soil erosion. Cereal growers may predict that their soil is acidic when acid sensitive crops fail to establish, or crop production is lower than expected, particularly in dry years. In pasture paddocks poor establishment or lack of persistence of acid sensitive pastures such as lucerne, and to a lesser degree phalaris, is an indication that the soil may be acidic.

More definitive indications of acidic soil are:

- stunted or shallow root growth in crops and pastures;
- poor nodulation in legumes or ineffective nodules; and
- manganese toxicity symptoms in susceptible plants.

A soil test is the most reliable way to assess if soils are acidic. Where soils are at risk of becoming acidic the future impact of soil acidity can be reduced, but not eliminated, by slowing the rate of acidification.

To slow the rate of acidification:

- minimise leaching of nitrate nitrogen
- use less acidifying fertilisers
- reduce the effect of removal of product
- prevent erosion of the surface soil

Application of finely crushed limestone, or other liming material, is the only practical way to neutralise soil acidity. Limestone is most effective if sufficient is applied to raise the pHCa to 5.5 and it is well incorporated into the soil. Where acidity occurs deeper than the plough layer, the limestone will only neutralise subsurface soil acidity if the pHCa of the surface soil is maintained above 5.5. [10]

The economic benefits of lime

The benefits of lime prove to be not only economically significant but the consequence of improved soil quality and increased nutrient uptake makes cropping more sustainable. However, a liming scheme does not result in overnight success. The amelioration of acidified soils is a lengthy process but it is worthwhile in the retention of a healthy, vibrant and sustainable soil. The longer the beneficial effects of lime persist, the more the investment in liming becomes economically favourable. Subsoil constraints such as acidity result in decreased rates of root elongation and limit the plant's ability to access water and nutrients. Subsoil acidity is caused by the excess application of acidic substances such as ammonium fertilisers. Surface liming is a common practice for ameliorating topsoil acidity in the relatively short-term, but is generally slow in ameliorating subsoil acidity. When acidity is increased, important nutrients such as nitrogen (N) and phosphorus (P) are less available to plants, while nutrients only needed in trace amounts such as aluminium (Al) and manganese (Mn) are increased. This can lead to Al and Mn toxicity resulting in a dramatic decline of plant growth. Lime substantially reduces the level of exchangeable Al and exchangeable Mn while raising soil pH by about 1.0 unit. Liming soils can remove the toxicities of Al and Mn and, dependent on the extent of acidity and species, plants

9 Soilquality.org. Soil pH—South Australia, http://www.soilquality.org.au/factsheets/soil-ph-south-australia

10 B Upjohn, G Fenton, M Conyers (2005) Soil acidity and liming. Agfact AC. 19. 3rd edition. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/167209/soil-acidity-liming.pdf

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WATCH : GCTV8: Liming Acids Soils.

may differ in their response to soil amelioration with lime. [11] A pH level of 5.5 and 8 is often seen as the optimum value for the growth of the plants.

Liming schemes are an appropriate solution to this problem and ensure the longevity of soils that may be succumbing to acidity. The long-term residual benefits of limestone have been shown to extend for beyond 8–10 years and indicate that liming should be profitable in the long term. [12]

Subsoil moisture

Low levels of soil moisture at sowing can significantly increase financial risks. Paddocks with ground cover can retain moisture for longer, extending the time for planting after small rainfall events. Levels of starting soil water should also affect 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.

Paddock nutrition

Fertiliser is a major cost. Fertiliser rates to meet crop requirements may be modified if residual fertiliser from the last season remains. Paddock history, past crop performance, fertiliser test strips and soil tests can help to determine the most appropriate decision. It is not uncommon for paddocks to have multiple nutrition deficiencies, or variations in nutritional requirements, even with a similar cropping history.

See Section 5: Nutrition and fertiliser, for more information.

Weed burden and herbicide history

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 durum 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.

Paddocks planted to durum wheat should have a vigilant strategy for control of grass weeds in the preceding canola or pulse crops. Identify your 'cleanest' paddocks and consider the use of pre-emergent herbicides. Risk may be reduced through the combination of pre-sowing weed knockdown, late-sown (early-maturing) crops/varieties and pre-harvest desiccation in crops where registration is current. Weed management involves strategic herbicide applications in combination with other, non-chemical management options. Weed management in year one will affect the crop in year two.

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

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines, etc.) may be an issue in some paddocks and particularly low rainfall years (Photo 3). Remember that plant-back periods begin after rainfall occurs.

11 D Brooke, DR Coventry, TG Reeves, DK Jarvis (1989) Plant and Soil, 115, 1-6

12 M Quin (2015) Central West Farming Systems Inc., http://cwfs.org.au/2015/12/08/the-economic-benefits-of-lime/

Photo 3: *Effects of Group B herbicide residues on growth in barley and wheat.*

Source: DAFWA

See Section 6: Weed control for more information.

Disease carryover

Crop sequencing is an important component of long-term farming systems and contributes to the management of soil nitrogen (N) status, weeds, pests and diseases. Broad scale decisions on the sequence of crops include commodity prices, the short- and medium-term weather outlook, and the level of acceptable risk. In the paddock, considerations include soil moisture levels before planting, current and desired stubble cover, history of herbicide use, history of diseases, and the population level(s) of root-lesion nematodes. Crop sequences also affect the incidence and severity of major diseases of summer crops, especially those diseases that have several summer, and in some instances winter, crop hosts.

Crop sequencing is only a part of the integrated management of disease. 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. [13]

The previous crop will influence levels of both soil- and residue-borne diseases. Important diseases to consider include crown rot, take-all, yellow leaf spot, stripe rust, Barley Yellow Dwarf Virus (BYDV), Septoria blotch 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.

13 M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers 13 September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54t/a9ft5hf

Pests

Pests such as redlegged earth mites, blue oat mites, nematodes and, in some seasons, cutworms, aphids and armyworm may pose a risk in some paddocks. Aphids may also be vectors for transmission of diseases such as BYDV, particularly in higher rainfall environments. 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. [14]

See Section 7: Insect control for more information.

1.2 Paddock rotation and history

Crop rotations have an important role in managing water, disease, weed and nutrient cycles. [15] Rotations with non-cereal species, including pulses, canola, pasture legumes (especially lucerne), sorghum and sunflowers, are essential in order to:

- Manage root disease, especially crown rot
- provide for the biological fixation of N gas through legumes
- control weeds and contaminant crop species, and aid in herbicide group rotation.

Durum should be the first cereal crop after a non-cereal species. Avoid successive durum crops. [16] One advantage of using durum as part of a crop rotation is its relative resistance to the root lesion nematode *Pratylenchus thornei*, compared with other winter cereal crops. Durum crops in rotation will reduce the nematode count in the soil. But conversely, durum will more rapidly build up crown rot inoculum which can negatively affect subsequent winter cereal crops (Photo 4).

To achieve the high protein levels (desirable at least 13%) for durum, soil N management requires careful planning. Grain as low as 10% (DR3 quality grain) is accepted by marketers and end-users as blending can be done.

Ideally durum should be planted into a rotation following a grain or pasture legume phase. Alternatively the paddock's cropping history in conjunction with soil tests can be used to calculate a N budget. It is important to soil test for N to the effective rooting depth of the crop. N fertiliser is an expensive input for farming systems and it pays dividends to get the levels correct. Depending on location, requirements for other nutrients should also be met, including phosphorus, sulfur and—on highly alkaline soils— zinc. A robust crop rotation must be planned over a number of seasons if successful crops of durum wheat are to be produced. [17]

VIDEOS

WATCH: Over the Fence: The sweet benefits of legume rotations

14 N Border, K Hertel, P Parker (2007) Paddock selection after drought. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/126100/paddock-selection-after-drought.pdf

15 NSW DPI (2009) Setting up for high quality durum. Agriculture Today. NSW Department of Primary Industries, March 2009, http://www.dpi.nsw.gov.au/content/archive/agriculture-today-stories/ag-today-archives/march-2009/setting-up-for-high-quality-durum

16 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

17 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

Photo 4: *Durum showing crown rot damage. Rotations with non-cereal species, are important for reducing crown rot in durum crops.*

Source: GRDC

Crops such as wheat and barley leave behind relatively large quantities of stubble that will persist for some time. Pulse crops such as chickpea and field peas produce less stubble and because of their high N content they break down faster.

Crop rotations should aim to maintain stubble cover as much as possible. For this reason, crops producing low stubble cover should be followed by crops that will restore ground cover.

Crown rot causes significant losses in durum and survives from year to year in stubble residue. Crop rotation to non-host crops, such as pulses and oilseeds, reduces crown rot levels in paddocks by allowing time for the stubble to breakdown and disease levels to fall. A good crop rotation can increase the diversity of herbicides and weed control tactics that can be used throughout the whole rotation which aids the management of herbicide resistance. [18]

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.

Disadvantages of cereals as a rotation crop

Growing cereals in continuous production is not a recommende practice due to 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

18 NSW DPI (2009) Setting up for high quality durum. Agriculture Today. NSW Department of Primary Industries, March 2009, http://www.dpi.nsw.gov.au/content/archive/agriculture-today-stories/ag-today-archives/march-2009/setting-up-for-high-quality-durum

1.3 Tillage

Key points:

- Conservation farming involves reduced tillage, stubble retention and good rotations. This underpins sustainable grain production systems worldwide.
- Current advice on soil tillage management contains apparent contradictions. Some flexibility may be required in the application of conservation farming practices.
- No-till has revolutionised cropping, but has resulted in an increased reliance on herbicides, leading to herbicide-resistant weeds.
- A lack of tillage can cause nutrient stratification and favour diseases such as crown rot, *Rhizoctonia* and *Pseudomonas*.
- Conventional tillage can suppress plant parasitic nematode populations, lower the number of snails and slugs prior to canola crops and lower mice numbers in affected fields.
- From an overall systems perspective, limited and strategically timed tillage could have a tactical role as part of a productive, sustainable system. [19]

The practice of reduced tillage and stubble retention started 40 years ago following the development of the first knockdown herbicides. These practices meant a change from conventional cultivation, which at the time consisted of stubble burning and several passes with tines or discs to control weeds and produce a seedbed (Photo 5). Reduced cultivation and retained stubble led to improved soil structure and less soil erosion, and the environmental value of conservation cropping became more widely recognised. Many farmers adopted minimum tillage, which consisted of a single cultivation before sowing, generally with a tined implement, followed by seeding with a combine. Conventional cultivation, involving multiple passes, had largely disappeared by the mid-1980s. [20]

Photo 5: *The impact of tillage varies with the tillage implement used: inversion tillage using a mouldboard plough, as pictured here, results in greater impacts than using a chisel or disc plough.*

Source: Grains Research and Development Corporation

No-till is attractive to farmers because it reduces production costs relative to conventional tillage. However, some producers are reluctant to adopt this practice because it can have contrasting consequences on grain yield depending on weather conditions and other factors.

19 GRDC (2014) Strategic tillage fact sheet. Grains Research and Development Corporation, July 2014, www.grdc.com.au/GRDC-FS-StrategicTillage

20 J Midwood, Paul Birbeck. Managing heavy stubble loads and crop residue. In Managing stubble, Grains Research and Development Corporation, pp. 4–25

No-till improves moisture retention and soil structure, but can also contribute to increased incidence of soil and stubble-borne diseases, herbicide-resistant hard-to-kill weeds and stratification of immobile nutrients near the soil surface.[21]

Photo 6: *Strategic tillage can provide control for herbicide-resistant weeds and those that continue to shed seed throughout the year. Here it has been used for control of barnyard grass in fallow.*

Source: Grains Research and Development Corporation

1.4 Fallow weed control

Fallow management is not a major practice in the southern cropping region. Choosing paddocks with low levels of grass weeds (primarily herbicide resistant ryegrass and brome grass) is important due to durum's lower competitiveness and limited in-crop weed control options. [22]

Good weed control can be achieved effectively by:

- controlling weeds in preceding crops and fallow
- rotating crops and herbicides
- growing competitive durum crops
- the judicious use of herbicides.

Controlling weeds in both preceding crops and winter fallows is important for subsequent durum crop quality (Photo 7).

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 both important for good control of fallow weeds. For advice on individual paddocks growers should contact their local agronomist.

21 Y Dang, V Rincon-Florez, C Ng, S Argent, M Bell, R Dalal, P Moody, P Schenk (2013) Tillage impact in long term no-till. GRDC Update Papers. Grains Research and Development Corporation, February 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Tillage-impact-in-long-term-no-till

22 Tony Craddock (2016). Personal Communication.

Photo 7: *Fallow paddock. Weed control in fallow paddocks is important for subsequent durum crop yield and quality.*

Source: Tim Scrivener

For more information, see Section 6: Weed control

1.4.1 The green bridge

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 (Photo 8).

Photo 8: *Broad-leafed weeds and grasses form a green bridge between successive crops.*

Source: DAFWA

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.

MORE INFORMATION

Green bridge management fact sheet

- 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 neighbouring properties 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. [23]

1.4.2 Stubble retention

Key points:

- Retaining stubble has several advantages to soil fertility and productivity.
- Retaining stubble can decrease erosion and increase soil water content.
- Benefits of stubble retention are enhanced by reduced tillage and leguminous crop rotations.

Historically, stubble has been burnt in southern Australia because it creates easier passage for seeding equipment, enhances seedling establishment of crops, and improves control of some soil-borne diseases and herbicide resistant weeds. However, the practice of burning stubble has recently declined due to concerns about soil erosion, loss of soil organic matter and air pollution. However, stubble is increasingly being retained which has several advantages of soil fertility and productivity (Photo 9).

VIDEOS

WATCH: GCTV5: Managing summer fallow.

WATCH : Managing Stubble.

Photo 9: *Management of retained stubble is important for healthy crop rotations.*

Source: GRDC

Summer rainfall and warmer conditions promote decomposition of stubble.

Other benefits of stubble retention

Retaining stubbles returns nutrients to the soil, the amounts depend on the quality and quantity of stubble. Wheaten stubble from a high yielding crop may return up to 25 kg of available nitrogen per hectare to the soil. The addition of organic matter with retained stubbles supports soil life, and can improve soil structure, infiltration

MORE INFORMATION

Developments in stubble retention

23 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

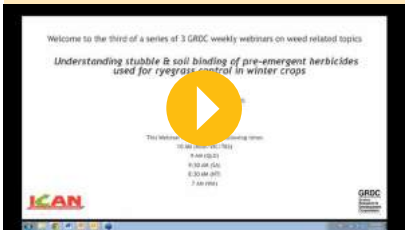
VIDEOS

WATCH: Stubble height part 1 and part 2.

WATCH : Southern farm groups cutting through stubble issues.

WATCH : Over the Fence south: Jim Cronin.

WATCH : Stubble and soil binding of pre-emergent herbicides for annual ryegrass control in winter crops.



and water holding capacity. These benefits are greater when integrated with no till practices.[24]

1.5 Herbicides and plant-back issues

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop. Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods. Some herbicides can remain active in the soil for weeks, months or years. This can be an advantage as 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.

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops etc.' heading in the 'General instructions' section of the label. [25]

It is important to note that product labels do not use consistent terminology or put warnings in the same place so you need to read the entire label carefully. A real problem for growers is the difficulty in identifying herbicide residues before they cause a problem. Currently, we are limited to predicting carryover based on information provided on the product labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if the 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. [26]

Table 1 lists common herbicides with some residual activity that may be of risk to durum crops.

Table 1: *Herbicides that pose a potential risk to durum crops. Current at publication of this GrowNote.*

Herbicide group	Active constituent
Group B: Imidazolinones	imazamox, imazapic, imazapyr, imazethapyr
Group B: Triazolopyrimidines (sulfonamides) (Lower risk)	flumetsulam, florasulam, metosulam, pyroxsulam
Group C: Triazines	atrazine, simazine
Group C: Triazinones	metribuzin
Group C: Ureas	diuron
Group H: Pyrazoles	pyrasulfotole
Group H: Isoxazoles	isoxaflutole
Group K: Chloroacetamides	dimethenamid, metholachlor
Group K: Isoxazoline	pyroxasulfone NOTE: Important to note that durum is more sensitive to this Active constituent than bread wheat.

Source: Agriculture Victoria

24 Soilquality.org. Benefits of retaining stubble – NSW. http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

25 DPI NSW. (2008). Herbicide residues in soil and water. http://www.smarttrain.com.au/__data/assets/pdf_file/0008/351863/Herbicide-Residues-in-Soil-and-Water.pdf

26 DEDJTR (2013) Avoiding crop damage from residual herbicides, Department of Economic Development, Jobs, Transport and Resource, August 2013, 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

Most herbicide residues are broken down by microbial activity in the soil. The soil microbes require warm, moist soil to survive and "feed" on the chemical. Degradation of chemical residue is slower when soils are dry or cold. Soil type and pH also have an influence on the rate at which chemicals degrade. [27]

Note that label plant-backs are important particularly for durum wheat as it can be more sensitive to residues of some herbicides than bread wheat. Residues can lead to crop stunting and delayed growth and poor establishment. [28]

Conditions required for breakdown

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

In those areas that do not experience conditions which will allow breakdown of residues until just prior to sowing, it is best to avoid planting a crop that is sensitive to the residues potentially present on the paddock, and opt for a crop that will not be affected by the suspected residues.

If dry areas do get rain and the temperatures become milder, then they are likely to need substantial rain (more than the label requirement) to wet the sub-soil, so the topsoil can remain moist for a week or more. This allows the microbes to be active in the top-soil where most of the herbicide residues will be found. [29]

Plant-back periods for fallow herbicides in the Southern Region

Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing winter crops in the Southern region. Many herbicide labels place time and/or rainfall restrictions on sowing certain crops and pastures after application, due to potential seedling damage. Crops such as canola, pulses and legume pastures are the most sensitive to herbicide residues, but cereal crops and especially durum wheat can also be affected.

When treating fallow weeds, especially in late summer or autumn, consideration must be given to the planned crop or pasture for the coming year. In some cases, the crop or pasture for the following year may also have an influence on herbicide choice.

Most herbicide residues are broken down by microbial activity in the soil. The soil microbes require warm, moist soil to survive and "feed" on the chemical. Degradation of chemical residue is slower when soils are dry or cold. Soil type and pH also have an influence on the rate at which chemicals degrade.

The following points are especially relevant:

- Phenoxy herbicides such as 2,4D Ester, 2,4D Amine and Dicamba, require 15 mm of rainfall to commence the plant-back period when applied to dry soil.
- Group B herbicides such as Ally, Logran and Glean break down more slowly as soil pH increases. Recently applied lime can increase the soil surface pH to a point where the plant-back period is significantly extended.
- Lontrel, Grazon and Tordon products break down very slowly under cold or dry conditions, which can significantly extend the plant-back period.

27 RMS (2016) Plant-back periods for fallow herbicides in southern NSW. Rural Management Strategies Agricultural Consultants, April 2016, http://www.rmsag.com.au/2016/plant-back-periods-for-fallow-herbicides-in-southern-nsw/

28 DEDJTR (2013) Avoiding crop damage from residual herbicides, Department of Economic Development, Jobs, Transport and Resource, August 2013, 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

29 Dow AgroSciences. Rotational crop plant-back intervals for southern Australia. http://msdssearch.dow.com/PublishedLiteratureDAS/dh_0931/0901b80380931d5a.pdf?filepath=au&fromPage=GetDoc

Keeping accurate records of all herbicide treatments and planning crop sequences well in advance can reduce the chance of crop damage resulting from herbicide residues (Table 2). [30]

Table 2: *The below table provides indicative plant-back intervals for a selection of relevant herbicides.*

Product	Rate	Plant-back period	Wheat	Barley	Oats	Canola	Legume Pasture	Pulse Crops
2,4-D 680*	0–510 ml/ha	(days)	1	1	1	14	7	7
	510–1,150 ml/ha		3	3	3	21	7	14
	1,150–1,590 ml/ha		7	7	7	28	10	21
Amicide Advance 700*	0 – 500 ml/ha	(days)	1	1	1	14	7	7
	500 - 980 ml/ha		3	3	3	21	7	14
	980–1500 ml/ha		7	7	7	28	10	21
Kamba*	200 ml/ha	(days)	1	1	1	7	7	7
	280 ml/ha		7	7	7	10	14	14
	560 ml/ha		14	14	14	14	21	21
Hammer 400 EC					No	Residual	Effects	
Nail 240 EC					No	Residual	Effects	
Goal					No	Residual	Effects	
Striker					No	Residual	Effects	
Sharpen	26 g/ha	(weeks)	-	-	-	16	-	-
Lontrel	300 ml/ha	(weeks)	1	1	1	1	36	36
Garlon 600		(weeks)	1	1	NS	NS	NS	NS
Ally		(weeks)	2	6	36	36	36	36
Logran #		(months)	-	-	-	12	12	12
Glean		(months)	-	9	6	12	12	12
Grazon Extra /Grazon DS		(months)	9	9	NS	9	24	24
Tordon 75D, Tordon 242		(months)	2	2	NS	4	9	6
Tordon Fallow Boss		(months)	9	9	NS	12	20	20

Table key:
* 15 mm rainfall required to commence plant-back period
Period may extend where soil pH is greater than 7
\# Assumes 300 mm rainfall between chemical application and sowing
NS Not Specified

Source: RMS

For more information on herbicide residues, see Section 6: Weed control.

1.6 Seedbed requirements

One of the first ways to achieve high yields in durum wheat is to seed the crop into a clean seedbed to reduce competition for moisture and nutrients.

Wheat seed needs good soil contact for germination. This can be assisted with press wheels, coil packers or rollers. Soil type determines the implement that produces the ideal seedbed. Between 70 and 90% of seeds sown produce a plant if vigour and germination are high. Depth of sowing, disease, crusting, moisture and other stress in the seedbed all reduce the number of plants establishing. Field establishment is unlikely to be more than 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, as the clods allow light to penetrate below the soil surface.

MORE INFORMATION

Herbicide residues in soils – are they an issue?

Weed control in winter crops.

30 RMS (2016) Plant-back periods for fallow herbicides in Southern-NSW, http://www.rmsag.com.au/2016/plant-back-periods-for-fallow-herbicides-in-southern-nsw/

The coleoptile senses the light and stops growing while still below the surface. For successful crop establishment, seed needs to be placed into soil with enough seedbed moisture for germination to occur, or into dry soil with the anticipation of rainfall to increase soil moisture levels such that germination may occur. [31]

Ground preparation is the same as for bread wheat. Adequate cultivation and/or spraying should eliminate all volunteer plants of bread wheat, barley and other crop/weed species. [32]

A good seedbed should be weed, disease and insect free. It should provide good seed/soil contact and be moist and warm. To aid in erosion control use implements that will preserve the previous crop residue. Substituting herbicides for cultivation and seeding without pre-seeding tillage (minimum to zero till) are other practical considerations. Under dry or firm soil conditions, seed with seeding implements that minimize soil disturbance, such as air drills with disc or narrow openers, to prevent soil drying.

When shallow seeding, the previous crop's residue will have a greater tendency to interfere with good seed-to-soil contact. Even spreading of the previous crop residue is essential for quick emergence. Make sure seed-to-soil contact occurs. When seeding on summer fallow, take extra care to obtain a firm seedbed to facilitate shallow seed placement into moist soil and to prevent soil erosion by wind.

If irrigating, pre-irrigation is favoured over "irrigating up" after sowing, as seeds can swell and burst. Sowing after pre-irrigation should be as soon as soil conditions allow. For an April 1st pre-irrigation, this delay may range from one week on light soils to 3–4 weeks on some heavy clay soils.

Following the initial irrigation, subsequent irrigations should be at a cumulative evaporation less rainfall interval (E-R) of 75 mm on grey soils and 50 mm on red soils.

Pre-irrigation completed by April 1st is a safe option in most years. Later irrigations can cause problems by making the ground too wet for both sowing and grazing.

If not pre-irrigated, then the crop should be sown following sufficient rainfall to wet the soil to 100 mm depth. [33]

There are several approaches that can be used to achieve a good seedbed preparation. The deciding factor in choosing an approach is how the various techniques manage harvest residues.

The seedbed lays the foundations for crop establishment. However, there are different techniques that can be used to create a seedbed. The technique used depends on many different factors, e.g. harvest residues, the equipment available, soil type, climate, labour requirement, etc (Figure 2).

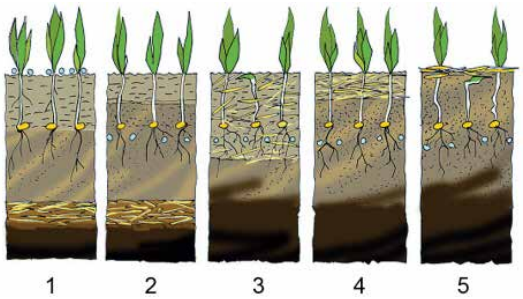


Figure 2: *Diagram demonstrating the results of different seedbed preparation options.*

Source: Vaderstad

31 NSW DPI (2008) Wheat growth and development (Eds J White, J Edwards). New South Wales Department of Primary Industries, February 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/516185/Procrop-wheat-growth-and-development.pdf

32 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

33 Agriculture Victoria. Managing winter cereals, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/irrigated-pastures/managing-winter-cereals

The seedbed and sowing using different techniques:

1. Conventional technique: ploughing in of straw, cultivation to sowing depth with a tyne/disc cultivator, conventional drilling, fertiliser spreading.
2. Mouldboard ploughing: Ploughing in of straw.
3. Minimal tillage: tillage of straw by cultivator.
4. Shallow tillage: shallow burial of straw at the surface.
5. Direct drilling: The straw remains on the surface.

Ploughing warms up the soil and buries plant residues so that they do not obstruct sowing. However, ploughing disrupts the soil structure and increases oxidation of the organic material. Without ploughing, the organic material and the soil structure are retained, but the straw can cause problems with sowing and can transmit diseases. [34]

1.6.1 Seedbed soil structure decline

Key Points

- Hard-setting or crusting soils are usually indicators of poor soil structure.
- A "massive" soil has significantly reduced pore space resulting in poor infiltration and low water holding capacity.
- Bulk density is a good indicator of soil structure.
- Increasing organic matter and decreasing traffic and stock can improve soil structure.
- Gypsum can help in alleviating problems with hard-setting or crusting.

Background

Surface soil structure decline generally results in one of two things: hard-setting or crusting (Photo 10). A surface crust is typically less than 10 mm thick and when dry can normally be lifted off the loose soil below. Crusting forces the seedling to exert more energy to break through to the surface thus weakening it. A surface crust can also form a barrier, reducing water infiltration.

Soil structure breakdown caused by rapid wetting can lead to hard-setting. Once wet, the unstable soil structure, collapses, and then shrinks as it dries. This leads to a "massive" soil layer with little or no cracks and greatly reduced pore space. This hard-set "massive" structure is associated with poor infiltration, low water holding capacity and a high soil strength. In many instances, this causes patchy establishment and poor crop and pasture growth.

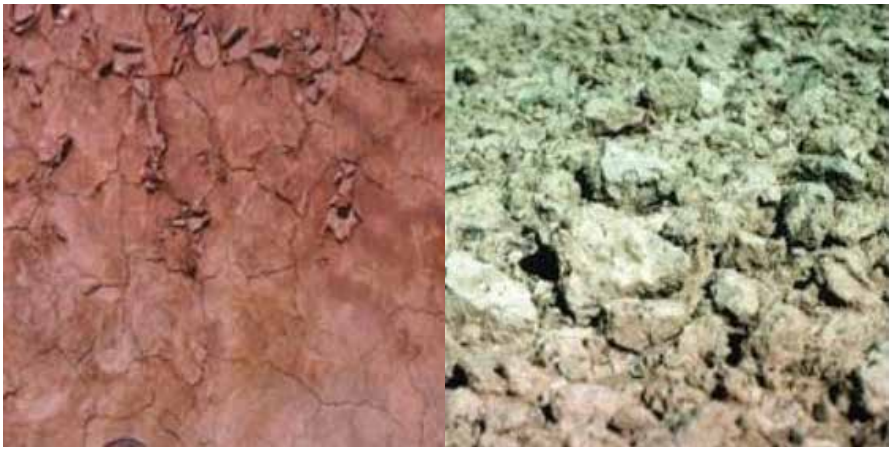


Photo 10: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium.*

Source: Soilquality.org

34 Vaderstad. Seedbed Preparation, http://www.vaderstad.com/knowhow/seed-beds/seedbed-creation

Management to improve seedbed soil structure

To decrease the level of crusting or hard-setting in soils, it is necessary to stabilise soil structure. For example, amelioration of a hard-setting grey clay was found to be most effective using management practices that increased soil organic matter and reduced trafficking, thereby improving soil structure. Removing or reducing stock when the soil is saturated also helps avoid compaction, smearing and "pugging" of the soil surface.

Another option for stabilising soil structure in soils prone to hard-setting or crusting is through the addition of gypsum on dispersive soils. This effectively displaces sodium, and causes clay particles to bind together, helping to create stable soil aggregates. A resulting reduction in the exchangeable sodium percentage (ESP) and increase in the calcium/magnesium ratio may be observed. Addition of lime also adds calcium to the soil, but is generally only used for soils with a low pH. [35]

1.7 Soil moisture

Soil characteristics (surface and subsurface) such as pH, sodicity, salinity, acidity, texture, drainage and compaction will affect variety selection. See your local variety guide for details of recommended varieties and planting times. There is significant variation in soil type across the southern region.

1.7.1 Dryland

Soil moisture

Low levels of soil moisture at sowing can significantly increase financial risks. Water is often the limiting factor in crop production and crop rotation can help maximise water intake by soil. Surface cover (stubble) is essential for this process. While around 20% of rain is stored during fallows, small changes in soil management can improve this apparent low efficiency and have large impacts on profit. Water stored can be improved through weed control, soil cover and reduced compaction. This can be achieved through reduced tillage, controlled traffic and planting crops before the soil fills. Paddocks with ground cover can retain moisture for longer, extending the time for planting after small rainfall events. Stubble retention combined with reduced or zero tillage almost universally results in better water storage. Better water storage results in better yields, especially in dry years. [36] After drought, it is important to restore ground cover as soon as possible to get the water cycle working again. [37]

Soil salinity

A saline soil is one that contains sufficient soluble salts (most commonly sodium chloride [NaCl]) to adversely affect the growth of most plants. Salinity reduces a plant's ability to extract water from the soil and can cause toxicities from specific ions. Salt tolerance in the genus *Triticum* is associated with low accumulation of sodium (Na+) in leaves. Durum and other tetraploid wheats generally have high accumulation of Na+ relative to bread wheat, and are salt-sensitive.

Salinity that effects crop growth is associated with water tables and susceptibility to waterlogging in south-east South Australia (SA), whilst most cropped soils in Victoria and SA have the potential to experience transient salinity associated with excess rainfall occurring in sodic soils. The economic effect of salinity in agriculture is considerable, being estimated at $1.5 billion annually for the whole of Australia. An exception is in the higher rainfall environment of southern Victoria where salinity is not considered a major factor effecting productivity of grain crops. [38]

35 Soilquality.org. Seedbed soil structure decline, www.soilquality.org.au/factsheets/seedbed-soil-structure-decline

36 D Freebairn (2016) Improving fallow efficiency. GRDC Update Papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Improving-fallow-efficiency

37 NSW DPI (2009) Setting up for high quality durum. Agriculture Today. NSW Department of Primary Industries, March 2009, http://www.dpi.nsw.gov.au/content/archive/agriculture-today-stories/ag-today-archives/march-2009/setting-up-for-high-quality-durum

38 Crop Pro (2003) Physical and chemical soil constraints of wheat crops in southern Australia.

Signs of salinity in the paddock:

- crop symptoms including reduced yield, and burnt leaf tips and/or margins (Photo 11)
- salt-tolerant plant species thriving while others show poor growth
- dieback of trees
- waterlogged soil (separate from rain or flood events)
- bare patches of soil
- wet, dark, greasy patches
- salt crusts on the soil surface when it is dry
- stock congregating and licking surface salt
- very clear water in dams and waterways. [39]

Photo 11: *Cereal plant with salinity symptoms.*

Source: Department of Agriculture and Food Western Australia

Genetics: building salt tolerance

CSIRO scientists developed a salt-tolerant, premium-priced durum wheat that yields 25% more grain than the parent variety in previously unsuitable saline soil. [40] Research revealed that an ancient Persian durum wheat has the ability to exclude salt from its roots. Elite lines derived from crosses between Tamaroi(D) and the sodium-excluding ancestors were grown in saline and non-saline soils for the first time in the 2004 season. The Durum Breeding Australia project (NSW Department of Primary Industries and the University of Adelaide) and researchers at CSIRO Plant Industry Canberra identified two major genes that confer the salt tolerance, and a molecular marker has been found for one. There is ongoing research to find a marker for the other. The research is being conducted through the AUSGRAINZ joint venture between CSIRO and New Zealand Crop and Food Research (GRDC Research Codes: CSP344, CSP298, CSP00058). [41]

39 S. Alt (2016). Salinity – New South Wales. Soil Quality Fact Sheets, http://www.soilquality.org.au/factsheets/salinity-nsw

40 University of Adelaide (2012) World breakthrough on salt-tolerant wheat. University of Adelaide, March 2012, https://www.adelaide.edu.au/news/news51221.html

41 GRDC (2005) Tracking Water Use Efficiency. GRDC Groundcover Issue 54. Grains Research and Development Corporation, February 2005, http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-54/Tracking-wateruse-efficiency

IN FOCUS

Impact of ancestral wheat sodium exclusion genes Nax1 and Nax2 on grain yield of durum wheat on saline soils. [42]

Nax1 and Nax2 are two genetic loci that control the removal of Na+ from the xylem and thereby help to exclude Na+ from leaves of plants in saline soil. They originate in the wheat ancestral relative *Triticum monococcum* L. and are not present in modern durum or bread wheat. The Nax1 and Nax2 loci carry TmHKT1;4-A2 and TmHKT1;5-A, respectively, which are the candidate genes for these functions. This paper describes the development of near-isogenic breeding lines suitable for assessing the impact of the Nax loci and their performance in controlled environment and fields of varying salinity. In young plants grown in 150 mM NaCl, Nax1 reduced the leaf Na+ concentration by three-fold, Nax2 by two-fold and both Nax1 and Nax2 together by four-fold. In 250 mM NaCl, Nax1 promoted leaf longevity and greater photosynthesis and stomatal conductance. In the uppermost leaf, the Na+-excluding effect of the Nax loci was much stronger. In the field, Na+ in the flag leaf was reduced 100-fold by Nax1 and four-fold by Nax2; however, Nax1 lines yielded 5–10% less than recurrent parent (cv. Tamaroi(b)) in saline soil. In contrast, Nax2 lines had no yield penalty and at high salinity they yielded close to 25% more than Tamaroi(b), indicating this material is suitable for breeding commercial durum wheat with improved yield on saline soils.

Subsoil

Subsoils are typically defined as below the plough layer, although some references imply below the A1 horizon or soil profile greater than 10 cm. The nature and impact of particular subsoil constraints (SSCs) in the southern region is strongly related to soil type and soil pH, particularly Vertosols, Calcarosols, Tenosols and Sodosols with alkaline subsoils, and acidic Chromosols and Sodosols. Crop types differ in their relative tolerance to different subsoil constraints, and the relative impact that constraints have on grain yield is heavily dependent on soil (especially subsoil) moisture. The general nature of subsoil physicochemical properties is relatively uniform across all the neutral-alkaline soils in the low to medium rainfall regions of SA and Victoria and the southern Mallee. However, an unexpected trend towards lower boron concentrations has been identified in SA.

Field research conducted under dry seasonal conditions in the low rainfall environments of the Eyre Peninsula and Victorian Mallee and the medium rainfall environment of the southern Wimmera indicate there are few, if any, subsoil amelioration strategies that will reliably increase grain yields and profitability of cropping. All these regions were characterised by sodic, high-clay, neutral-alkaline soils and experimentation was conducted under extremely dry (Decile 1 to 4) seasonal conditions.

In contrast there is evidence (obtained via simulation modelling and controlled environment trials) that under better seasonal conditions some of these subsoil amelioration strategies could significantly improve grain yields. Similarly, in environments with sand-over-clay soils (in both low and medium rainfall regions) there were consistent yield responses to deep ripping/nutrient placement. The current

42 RA James, C Blake, AB Zwart, RA Hare, AJ Rathjen, R Munns (2012). Impact of ancestral wheat sodium exclusion genes Nax1 and Nax2 on grain yield of durum wheat on saline soils. Functional Plant Biology, 39(7), 609–618, http://www.publish.csiro.au/paper/FP12121.htm

financial viability of this strategy was questionable, however, and further work is required to develop more cost-effective strategies. [43]

GPS mapping and empirical modelling techniques have been used to determine the relationships between the wheat and soil factors. Areas within the field with lower soil profile available water capacities, caused by a combination of coarser soil texture and lower organic carbon content, probably contributed to water stress during grain-fill, which interacted with soil N to give higher protein levels. These areas of the field had lower yields and smaller 1000-kernel weights. Protein quality was not compromised by increasing protein concentrations which resulted from water stress. [44]

Genetic solutions to subsoil constraints

The potential contribution of genetic variation to improving crop production on hostile subsoils has been assessed. Closely-related genotypes of bread and durum wheat, barley and lentil with differing tolerances to boron (B) and/or Na+ were compared by growing the different lines in intact soil cores of two Calcarosol profiles with differing levels of subsoil physicochemical constraints ('hostile'/'benign') from the southern Mallee.

Grain yields were significantly reduced on the hostile soil compared with the benign soil, with durum wheat yielding 31% less on the hostile soil. Durum wheat (genotype with greater Na+ tolerance) did not show significant yield advantage compared to the respective 'non-tolerant' parent line when grown on the hostile soil. This work suggests there is little benefit in lines with tolerance for a single specific subsoil constraint where there are multiple potential constraints. In contrast, lentils possessing tolerance to both high Na+ and B show considerable promise for improving yields on these soils. This experiment also highlighted the potential benefit of pyramiding tolerances to specific SSCs. [45]

1.7.2 Irrigation

Durum can be grown successfully under irrigated conditions using both surface and overhead irrigation systems. [46] Both water and N management are crucial if high yielding crops of high quality grain are to be achieved (Figure 3). [47]

Although irrigation of wheat generally leads to an increase in biomass and grain yield, it can have negative effects on grain quality. Usually the kernels become larger with irrigation (depending on the duration and frequency) than under rain-fed farming, and this causes a dilution of grain protein and yellow pigment and an increase in yellow berry (lower percentage of hard vitreous kernels [HVK]), which is associated with lower semolina extraction. This can be corrected by increasing N application at sowing, and especially by splitting application between stem elongation and heading. [48] More N translates into more grain protein, thereby reducing yellow berry incidence, which is inversely related to grain protein content. [49] N fertilisation generally increases grain protein content, gluten content, HVK, carotenoids and the dough strength (as assessed by sodium dodecyl sulfate (SDS) sedimentation) if soil available N is deficient. [50]

43 GRDC (2008) Improving the profitability of cropping on hostile subsoils – DAV00049. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAV00049

44 CM Stewart, AB McBratney, JH Skerritt (2002) Site-specific durum wheat quality and its relationship to soil properties in a single field in northern New South Wales. Precision Agriculture, 3(2), 155–168, DOI: 10.1023/A:1013871519665

45 GRDC (2008) Improving the profitability of cropping on hostile subsoils – DAV00049. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAV00049

46 Rharrabti et al. (2001), Reynolds et al. (2002), Karam *et al.* (2009), and Mohammadi *et al.* (2011).

47 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

48 CA Grant, N Di Fonzo, M Pisante (2012) Agronomy of durum wheat production. In Durum wheat chemistry and technology. 2nd edn (Eds M Sissons, J Abecassis, B Marchylo, M Carcea) pp. 37–55. (AACC International: St. Paul, MN, USA)

49 M Sissons, J Abecassis, B Marchylo, R Cubadda (2012) Methods used to assess and predict quality of durum wheat, semolina and pasta. In Durum wheat chemistry and technology. 2nd edn (Eds M Sissons, J Abecassis, B Marchylo, M Carcea) pp. 213–234. (AACC International: St. Paul, MN, USA)

50 L Ercoli, L Lulli, M Mariotti, A Masoni, I Arduini (2008) Post-anthesis dry matter and nitrogen dynamics in durum wheat as affected by nitrogen supply and soil water availability. European Journal of Agronomy, 28, 138–147. http://dx.doi.org/10.1016/j.eja.2007.06.002

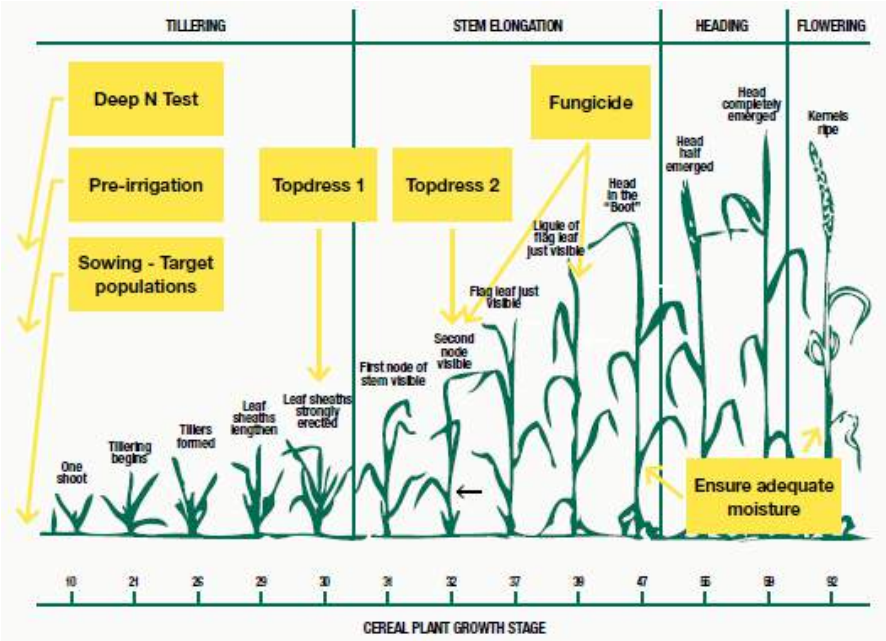


Figure 3: *Irrigated wheat management practices by growth stage. If sowing early, it is vital the crop is not moisture stressed at head emergence or during the first 10 days after flowering—these are the critical stages for determining grain number and size. Other key management practices include timing of nitrogen application.*

Source: Grains Research and Development Corporation

MORE INFORMATION

Irrigated wheat in the Murrumbidgee and Murray Factsheet.

In field trials conducted under irrigated conditions, durum varieties Arrivato(Ɒ and Bellaroi(Ɒ yielded well and appear well suited to the high-yielding irrigation environment. Late topdressing of N was evaluated on Arrivato(Ɒ at Griffith (on-farm test strips) and demonstrated the difficulty in reaching required quality at 8 t/ha or more. [51]

51 GRDC (2005) Wheat variety evaluation for irrigation in the southern region – CSP342. Grains Research and Development Corporation, http://finalreports.grdc.com.au/CSP342

IN FOCUS

Durum wheat quality in high-input irrigation systems in south-eastern Australia. [52]

Durum wheat is primarily grown under non-irrigated conditions. To help extend the production base of durum wheat in Australia, field trials have been conducted on seven registered durum varieties across four seasons and six sites in locations where irrigation was supplied during crop growth. This was done to determine if the quality of the grain produced met the requirements for good milling and pasta-making quality and to understand the genotype, environment and their interaction in affecting yield and technological quality of the grain and derived pasta.

High grain yields and grain protein were obtained, producing large grain weights, low screenings and low percentage of HVK. Yellow colour of semolina and pasta was reduced marginally but dough and other pasta technological characteristics were similar to typical dryland durum production, with some exceptions.

High-yielding durum production can be achieved with irrigation and with appropriate N applications; 13% protein, the level required by pasta industry standards, is also achievable. The highest yielding variety was Hyperno(D), followed by EGA Bellaroi(D), whereas Jandaroi(D) was the lowest yielding. However, Hyperno(D) is more predisposed to lodging, and the varieties EGA Bellaroi(D) and Arrivato(D) had the best lodging scores (but with a poor yellow score). Excellent grain size is a feature of irrigated wheat, but the downside was the low HVK, with EGA Bellaroi(D) performing the best but still not attaining ADR1 grade. Yellowness of the semolina and pasta was lower than obtained in typical dryland production, with the best varieties being EGA Bellaroi(D), Hyperno(D) and Caparoi(D). Pasta quality from irrigated durum was similar to typical dryland durum, having acceptable cooking and texture properties except for a reduction in pasta yellowness. Significant genotype, location and genotype × location effects for all of the technological characteristics were quantified. Breeding selection under irrigation might be a useful strategy to improve semolina yield, protein content, grain yield, and semolina and pasta colour, because irrigation and suitable N provide more stable conditions for varietal selection.

1.8 Yield and targets

Yield potential (as opposed to achieved yield) is determined in the growth phase before anthesis, during the formation and growth of the ear. Yield potential can best be thought of in terms of the number of grains per unit area and the size (weight) of each grain. There are several critical times during crop development where grain number and size are determined. The first step in establishing yield potential is that of crop establishment; i.e. how many plants per square metre, as this directly affects the number of heads per square metre a crop can produce. [53]

52 M Sissons, B Ovenden, D Adorada, A Milgate (2014). Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

53 N Poole, J Hunt (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

Management factors to build a crop structure for achieving high yields:

1. Soil conditions allowing good root structure development.
2. Variety with stem and straw strength.
3. Sowing at the correct sowing window.
4. Flowering during a period to avoid potential low and high temperature stress.
5. Restricting tillering to attain 600 to 800 shoots per square metre.
6. Limited early growth with less than 70% ground cover at early stem elongation.
7. Avoiding water stress during stem elongation to maintain highest yield potential.
8. More than three green leaves per shoot at flowering to maintain the highest yield potential. [54]

A study monitored eight commercial durum crops to identify the factors limiting durum wheat yields and the levels for target yields. Low plant population (42–91 plants/m^2) resulting from poor seed quality (60–95% germination), combined with insufficient nitrate supply (3–27 kg N/ha at harvest at four of five sites), appeared to be major factors limiting durum yields in the monitored crops (range 4.3–5.3 t/ha). Disease management was also likely to be a contributing factor, as crown rot levels in the wheat paddocks were <5% following sorghum and 15–30% following wheat. [55]

Accurate, early estimations of grain yield and crop loss are important skills in grain production. Extensive personal experience is essential for estimating yields at early stages of growth. As crops near maturity, it becomes easier to estimate yields with greater accuracy. A simple but accurate formula for estimating cereal grain yield is based on the number of heads per 500 mm of drill row, the number of grains per head and the size of the grain.

Formula for estimating grain yield:

$$\frac{\text{Average number of grains per head} \times \text{Average number of heads per 500 mm of row}}{\text{Known constant (K)}} = \text{tonnes/hectare}$$

MORE INFORMATION

Estimating crop yields

Yield Prophet®

Scientists have aimed to support farmers' capacity to achieve yield potential by developing the Agricultural Production Systems Simulator (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 delivers information from APSIM to farmers (and consultants) to aid their decision-making. Yield Prophet has enjoyed a measure of acceptance and adoption amongst innovative farmers and has made valuable impacts in terms of assisting farmers to manage climate variability at a paddock level.

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 decision-support relevant to farm management.

Operated as a web interface for APSIM, Yield Prophet generates crop simulations and reports to assist decision-making. By matching crop inputs with potential yield in a given season, Yield Prophet subscribers may avoid over or under-investing in their crop.

54 GRDC (2005) Wheat variety evaluation for irrigation in the southern region – CSP342. Grains Research and Development Corporation, http://finalreports.grdc.com.au/CSP342

55 GJ Butler, PT Hayman, DF Herridge, T Christian (2001) Working with farmers to benchmark high-yielding durum wheat on the Liverpool Plains. 10th Australian Agronomy Conference, 31 January 2001, Hobart, Tasmania, http://www.regional.org.au/au/asa/2001/4/b/butler.htm

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

Farmers and consultants use Yield Prophet to match crop inputs with potential yield in a given season. 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.

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 (BOM) weather station
- paddock-specific rainfall data recorded by the user (optional)
- individual crop details
- fertiliser and irrigation applications during the growing season

MORE INFORMATION

Yield Prophet

1.8.1 Seasonal outlook and crop modelling tools

Though weather patterns can be unpredictable, it is important to stay up-to-date with seasonal forecasts. Growers and advisers now have a readily available online tool. CropMate (Figure 9) 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 N, frost and heat risk, as well as gross margin analyses of the various cropping options.

Download CropMate from the iTunes store.

Figure 4: *Screen shot of the CropMate app.*

Source: NSW Department of Primary Industries

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 Nino-SOI status. It is designed for decision makers such as farmers whose businesses rely on the weather. One of the CliMate tools, 'Season's progress?', uses long-term (1949 to present) weather recods to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years. It explores readily-available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons.

Download CliMate from the iTunes store or visit the CliMate website.

1.8.2 Fallow moisture

Fallow periods are not common practice in the southern durum cropping region, however, this information may be of use to some growers. For a growing crop there are two sources of water: first, the water stored in the soil during the fallow; and second, the water that falls as rain while the crop is growing. Growers have some control over the stored soil water, in that the amount of stored water can be measured 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 you need it. [56]

HowWet?

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

HowWet?:

- estimates how much rain has been stored as PAW during the most recent fallow period
- estimates the N mineralised as nitrate-N in soil
- provides a comparison with previous seasons.

This information aids in the decision about what crop to plant and how much N fertiliser to apply.

1.8.3 Water Use Efficiency

Greater yield per unit rainfall is one of the most important challenges in dryland agriculture. Water Use Efficiency (WUE) is the ratio of grain yield to crop water use, and a 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.

WUE relies on:

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

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.

While the French and Schultz method for calculating water use efficiency has known limitations, it remains a sound tool provided its limitations are understood and the right parameters are used. More recent research has shown that size of rainfall events, rather than total rain, drives soil evaporation. Known limitations include it does not account for timing of rainfall. The critical window around flowering is particularly important for grain set and shortage of water in this window causes large reductions in yield and water use efficiency. The notion of a single parameter representing maximum yield per unit water use and a single parameter representing soil evaporation is a simplification. Both parameters have large season-to-season variation. [57]

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

57 V Sandras and G McDonald (2011) Water use efficiency of grain crops in Australia: principles, benchmarks and management. Grains Research and Development Corporation. http://www.pir.sa.gov.au/__data/assets/pdf_file/0003/238413/SARDI-Water-Use-Efficiency-Grain-Crops-Australia.pdf

Ways to increase yield

In environments where yield is limited by water availability, there are four ways of increasing yield:

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).
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). [58]

WUE provides a simple means of assessing whether yield is limited by water supply or other factors. Yields of commercial dryland crops in south-eastern Australia are often limited by water. Transpiration efficiency (TE), the ratio of yield to transpiration, is relatively stable for well-managed crops, but the amount of water used is strongly affected by crop management. [59]

Calculating WUE:

Fallow efficiency: the efficiency with which rainfall during a fallow period is stored for use by the following crop.

$$\text{Fallow efficiency (\%)} = \frac{\text{change in plant available water during the fallow} \times 100}{\text{fallow rainfall (mm)}}$$

Crop water use efficiency: the efficiency with which an individual crop converts water transpired (or used) to grain.

$$\text{Crop WUE (kg/ha/mm)} = \frac{\text{grain yield (kg/ha)}}{\text{crop water supply (mm)} - \text{soil evaporation}}$$

Systems water use efficiency: the efficiency with which rainfall is converted to grain over multiple crop and fallow phases.

$$\text{SWUE (kg grain/mm rainfall)} = \frac{\text{total grain yield (kg)}}{\text{total rainfall (mm)}}$$

Providing optimum N fertiliser or suppressing root diseases with break crops has been found to increase water use by 23 mm and yields by 378 kg/ha, equivalent to 10% of the control yields. In the study, additional soil water was extracted to levels of water potential as low as -5 MPa. A possible means of increasing yield potential of dryland crops is to manage transpiration so that relatively more water is used during the vegetative phase when vapor pressure deficit is low, and hence TE is high. However, based on budgets of soil water and soluble carbohydrates stored in the vegetative organs and available for re-translocation, this option provides lower TE than conserving soil water for transpiration until grain filling when assimilates are directed to grain. Increasing the proportion of water transpired during the vegetative phase with N fertiliser can lead to particularly inefficient water use because increasing N status generally reduces the soluble carbohydrate reserves available for re-translocation to grain. [60]

58 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

59 JF Angus, AF Van Herwaarden (2001) Increasing water use and Water Use Efficiency in dryland wheat. Agronomy Journal, 93(2), 290–298, https://dl.sciencesocieties.org/publications/aj/abstracts/93/2/290

60 JF Angus, AF Van Herwaarden (2001) Increasing water use and Water Use Efficiency in dryland wheat. Agronomy Journal, 93(2), 290–298, https://dl.sciencesocieties.org/publications/aj/abstracts/93/2/290

Plant breeders in the Durum Breeding Australia project and researchers at CSIRO Plant Industry Canberra are developing water-use efficient and salt-tolerant durum wheats to increase durum yields in current production areas as well as new environments. Researchers are improving WUE by trying to combine several traits: high transpiration efficiency, long coleoptiles and early vigour. They have found, using 50 years of climate data and computer simulation, that combining high transpiration efficiency and early vigour is likely to make durum wheat much more suitable for growing in both southern and northern cropping areas. Elite durum varieties have low transpiration efficiency, but the research team has found a highly transpiration-efficient durum to cross with them. This will give the plants a WUE trait similar to that of the new bread wheats Drysdale(b) and Rees(b). The team is also introducing alternative dwarfing genes from European durum wheats into commercial varieties. These genes restrict plant height, but allow the expression of long coleoptiles (about 15 cm compared with 9 cm for Tamaroi(b)). Longer coleoptiles provide insurance that the shoot will reach the soil surface, even when deep sowing is required because of receding topsoil moisture, or when there is uneven sowing depth due to stubble or direct drilling. [61]

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.

> *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. [62]

In the wheat belt 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.

61 GRDC (2005) Tracking Water Use Efficiency. GRDC Groundcover Issue 54. Grains Research and Development Corporation, February 2005, http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-54/Tracking-wateruse-efficiency

62 GRDC (2009) Water Use Efficiency—Converting rainfall to grain. GRDC Fact Sheet. Water Use Efficiency Fact Sheet, GRDC, http://www.grdc.com.au/~/media/607AD22DC6934BE79DEAA05DFBE00999.pdf

Understanding how those climatic conditions affect crop processes and how they vary from south to north 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. [63]

1.8.4 Nitrogen Use Efficiency

Key points:

- Improving Nitrogen Use Efficiency (NUE) begins with identifying and measuring meaningful NUE indices and comparing them with known benchmarks, and contrasting N management tactics.
- Potential causes of inefficiency can be grouped into categories. Identification of the most likely groups is useful in directing more targeted measurement and helping identify possible strategies for improvement.
- As a result of seasonal effects, NUE improvement is an iterative process. Therefore, consistency in investigation strategy and good record keeping is essential. [64]

Nitrogen Use Efficiency (NUE) aims to quantify the amount of N fertiliser applied that is available to the crop. Achieving 13% protein in the new durum lines remains a major production challenge. As yields increase, protein levels are more than likely to decline within nitrogen-limited environments. [65] Improvements in NUE may be one method of improving the frequency in which growers achieve 13% protein. In benchmarking trials this value ranged from 25-95% in the benchmarked crops, which varies dramatically from the figure of 50% commonly used for N budgeting purposes. The major reason for the variation is the level of N that is tied up by trash, and the amount released by mineralisation. In the crops benchmarked, crops following cotton tended to have lower NUE, as the cotton trash that is incorporated into the soil requires large amounts of N to feed the microbes that break the trash down. In addition, there is minimal short-term, in-crop mineralisation. Crops following maize or fallow, however, had very little N tied up, and released much more N through mineralisation, and therefore had higher NUE. The amount of N removed was calculated by N in grain (kg/ha) = yield (t/ha) x 1.75 x protein (%), and crop N requirement = N in grain (kg/ha) x N uptake efficiency factor. So, if the starting soil N, the yield and the protein percentage is known, the N uptake efficiency factor can be estimated. [66]

1.8.5 Double crop option

Double cropping is growing a winter and summer crop following one another. Successful double cropping relies on careful planning of rotations, herbicide use and minimal hold-ups between harvesting and sowing. Durum has no or little evaluation in this system but would be expected to perform similarly to hard wheat, however variety choice and avoiding extremes of temperature at flowering will be critical for success with durum varieties.

There has been little adoption of double cropping in northern Victoria. Issues such as stubble management, conflict of harvest and sowing times between winter and

63 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

64 C Dowling C (2014) The fundamentals of increasing Nitrogen Use Efficiency, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/The-fundamentals-of-increasing-nitrogen-use-efficiency-NUE

65 GRDC (2012) Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DGA00001

66 B Haskins, M Sissons (2011) Growing wheat after cotton—durum benchmarking 2009. GRDC Update Papers. Grains Research and Development Corporation, August 2011,

summer crops, and difficulty in determining the best rotation of winter and summer crop options have been identified as barriers to adoption. Double cropping in northern Victoria could provide irrigation farmers with an opportunity to capitalise on their investment in irrigation infrastructure and improve their profitability and Water Use Efficiency.

A best practice management guide outlines nine key checks that must be undertaken to maximise the results of double cropping in northern Victoria. These are:

1. **Field layout, water delivery and drainage**: double cropping layouts need to be irrigated quickly and drained without delay. Use as a priority the paddocks with efficient channel delivery systems and reuse systems that allow drainage and eliminate farm runoff.
2. **Weed, pest and disease control**: use fallow, hay/silage and break crops to control weeds, pests and diseases. Determine weed densities and use integrated weed management to reduce the likelihood of herbicide resistance and limit yield loss.
3. **Opportunity cost of water**: determine the production costs of growing the crop. In low water allocation years, compare the market price of temporary trade water with the return on potential crop production. Use the opportunity cost *v.* commodity price matrix to determine best gross margin return for 1 ML of water.
4. **Sowing time:** a double cropping program can commence in either the summer or winter crop phase. The critical issue with crop sowing is timeliness—sowing on time to maximise yield potential, and to ensure harvest is complete before the optimal sowing window of the next crop phase.
5. **Soil moisture at sowing**: ensure there is adequate soil moisture for crop establishment and crop growth during the season. Determine subsoil moisture levels after the previous crop and pre-irrigate if required.
6. **Crop establishment**: achieve a uniform plant population using equipment necessary for good plant establishment. Some summer crops require the use of a precision planter. It is critical to the desired plant density for summer crops otherwise the economics of irrigation can be poor.
7. **Nutrition**: determine the soil nutrient status of paddocks by soil testing. Apply nutrients to the crop according to potential yield and product nutrient requirements.
8. **Irrigation**: double cropping is limited by water availability so efficient application is critical. Use soil moisture monitoring equipment to assist in determining root zone moisture levels. Use crop growth stage and weather patterns in conjunction with soil moisture levels to schedule irrigation.
9. **Timeliness of operations**: if necessary, use contractors with appropriate equipment to sow into potentially heavy stubble loads and for precision sowing to achieve optimum plant density. Contractors may also be required to harvest the crop in a timely manner so the next crop can be sown. [67]

The GRDC correct crop sequencing project will investigate rotations and techniques to provide results that will allow irrigators to be confident in investing their time and resources into double cropping. Research into double cropping funded by GRDC commenced with the winter 2014 season. It is a joint project between the Victorian Irrigated Cropping Council Inc (ICC) and NSW DPI. Each organisation has a different focus, with NSW DPI looking at rotations and ICC examining herbicide residues and techniques to reduce the intervals between the summer and winter crops.

67 D Boyd (2009) Double cropping in northern Victoria. A best management practice guide. Grains Research and Development Corporation, August 2009, http://www.dairyfertility.com.au/hgf/110405%20-%20Double%20Cropping%20in%20Northern%20Victoria.pdf

1.9 Disease status of paddock

Disease management of paddocks is essential for maximising yield. Research by the South Australian Research and Development Institute (SARDI) and GRDC is combining DNA technology with precision agriculture (PA) zoning techniques to provide grain growers with better risk assessment of soil-borne diseases before sowing crops.

The main findings so far are:

- Soil-borne pathogen levels usually vary between PA zones within a paddock, even when zones are created using simple PA layers (for example, EM38 maps, elevation maps).
- Robust sampling methods for soil tests are critical: the current recommendation is to collect 45 cores targeted where practical along the rows of the previous cereal crop. Target sampling within PA zones gives more useful information than samples taken across the whole paddock. [68]

1.9.1 Common diseases found

Crown rot and Fusarium head blight

Durum is very susceptible to crown rot and also sensitive to closely related Fusarium head blight (FHB), both of which can be present in paddocks prior to planting, although FHB is rarely found in the Southern Region.

The crown rot fungus enters the plant through the roots, disrupting plant water supply and hence grain yield. Moisture stress will exacerbate these conditions, resulting in the appearance of 'whiteheads' in the crop, which produce small shriveled grain. It is therefore recommended that durum crops not be grown following susceptible crops, which are carriers of *Fusarium sp*. [69]

Paddocks should contain very little crown rot inoculum. Ground known to carry high levels of crown rot inoculum should be sown to an alternative crop such as broadleaf crops (e.g. chickpea, faba bean, mungbean, canola, sunflower) over a period of two years before replanting durum. The sowing of a durum crop following bread wheat is not recommended, as inoculum will be increased by both susceptible species.

Though maize is not often grown in Southern regions, it is not advisable to plant maize in the rotation prior to durum, as maize is a susceptible host of the FHB fungus. Inoculum carried by the maize trash may pass the disease to the following durum crop if suitable weather conditions for infection, such as an extended wet period, prevail during and following flowering. [70]

To determine whether a paddock is at risk, visually assess crown rot and FHB levels in a prior cereal crop, check for stem browning or have soil/stubble samples analysed at a testing laboratory.

Effect 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. [71] Stubble burning is not recommended as a control for crown rot, and cultivation can increase 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 crown rot levels.

68 GRDC (2007) Spotlight on diseases. GRDC Groundcover Issue 58. Grains Research and Development Corporation, August 2007, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-58-Precision-Agriculture-Supplement/Spotlight-on-diseases

69 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

70 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

71 GRDC (2012) Crown rot. Grains Research and Development Corporation, July 2012, http://www.grdc.com.au/Media-Centre/Hot-Topics/Crown-Rot

Histories likely to result in high crown rot risk include:

- Durum wheat in the past one to three 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.
- Low rainfall during the last break from cereals.
- Paddocks with low stored soil moisture at grain fill will help to minimise yield loss.

See Section 9: Diseases for more information on crown rot.

1.9.2 Testing for disease

Soil sampling

Cereal root diseases cost grain growers in excess of $200 million a year in lost production. Much of this can be prevented.

PreDicta B (B = broadacre) is a DNA-based soil testing service that identifies which soil-borne pathogens pose a significant risk to broadacre crops prior to seeding. The test has been developed for cropping regions in southern Australia.

PreDicta B includes tests for:

- Cereal cyst nematode (*Heterodera avenae*).
- Take-all (*Gaeumannomyces graminis* var tritici (Ggt) and *G. graminis* var avenae (Gga)).
- *Rhizoctonia* barepatch (*Rhizoctonia solani* AG8).
- Crown rot (*Fusarium pseudograminearum* and *F. culmorum*).
- Root lesion nematode (*Pratylenchus neglectus* and *P. thornei*).
- Stem nematode (*Ditylenchus dipsaci*).

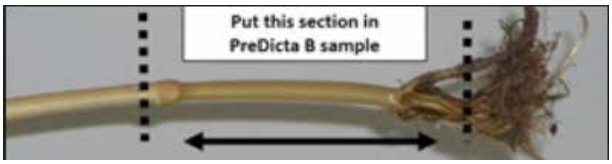


Photo 12: *Cereal stubble should be included in PreDicta B samples, if present, along with soil cores. Each piece of stubble should be from the base of the plant and include the crown to the first node (discard material from above the first node.*

Source: Grains Research and Development Corporation

MORE INFORMATION

PreDicta B Sampling strategy

You can access PreDicta B diagnostic testing services through a SARDI accredited agronomist. They will interpret the results and give you advice on management options to reduce your risk of yield loss. PreDicta B samples (Photo 12) are processed weekly between February to mid-May (prior to crops being sown) every year. These timeframes help assist you with your cropping program. PreDicta B is not intended for in-crop diagnosis—that is best achieved by sending samples of affected plants to your local plant pathology laboratory. [72]

Stubble assessment

Crown rot is a stubble-borne disease and for a plant to become infected it must come into contact with inoculum from previous winter cereal crops. Cultivation can spread the crown rot inoculum, increasing the chance of infection in the following cereal crop. [73] Knowing the initial inoculum levels in your stubble is critical in successfully managing crown rot. It is very important for crown rot testing to be carried out on stubble (Photo 13). It allows for growers and consultants to determine if there is crown

72 PIRSA (2015) Predicta B. Primary Industries and Regions South Australia, February 2010, http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b .

73 GRDC (2014) Managing crown rot. Grains Research and Development Corporation, June 2014, https://grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

rot present in a paddock and if so, how severe it is. An informed decision can then be made regarding crop choice and farming system. [74]

Photo 13: *Stubble infected with crown rot fungus. Notice the pink discolouration in and around the crown and under leaf sheaths.*

Source: SARDI

Sampling method

Using the sampling pack from Crown Analytical Services:

- Randomly select 10 plants per site at five sites in a W pattern across the paddock.
- At each site gently pull out, or dig, 10 plant stubble butts within about a 2 m radius. Shake off any excess soil but be careful not to damage the crown or bottom nodes.
- Trim stubble to a length of about 25 cm so that it will fit in the stubble bag.
- Place the stubble (50 plants) into the sample bag with the information sheet.
- Send samples back to Crown Analytical Services. [75]

1.10 Nematode status of paddock

Key points:

- Root-lesion nematodes (RLN) are species of *Pratylenchus* nematodes that feed on the roots of crops and can cause yield loss.

74 Crown Analytical Services. Crown Analytical Services – home, https://sites.google.com/site/crownanalyticalservices/home

75 Crown Analytical Services. Crown Analytical Services – protocol, https://sites.google.com/site/crownanalyticalservices/home/testing-process

- The main RLN species in the southern region are *Pratylenchus neglectus* and *P. thornei*.
- The *Pratylenchus* species present in the soil will affect choice of management practices, in particular rotations.
- RLN have a wide host range and can multiply on cereals, oilseeds, pulses and pastures as well as on broadleaf and grass weeds. [76]
- Durum wheat is also varyingly susceptible to cereal eelworm and cereal cyst nematode (CCN)

RLNs are tiny microscopic worms, about half a millimetre in length, that feed and reproduce in plant roots. This can lead to large yield losses in intolerant cereal and pulse crops. Nematodes invade the roots of growing plants. When nematode numbers are high, this can cause damage to the roots and affect nutrient and moisture uptake.

Populations of nematodes of 2000 nematodes per kilogram of soil is the threshold for yield loss in intolerant crops. At these levels or greater, growers need to choose a tolerant crop variety or rotate to a resistant crop according to the identified nematode species. [77]

RLN exacerbate the effects of crown rot, reducing the ability of the crop to extract soil water to deal with crown rot infection. [78]

1.10.1 Nematode testing

It is important to correctly identify the species of nematodes present due to differences in the susceptibility of break crops and varieties to different RLN. [79] Digging up plants and washing the roots can show black and brown-coloured root lesions, indicating tissue death. Whole sections of the root system may be dead. When nematode numbers are high, roots are often thin with little branching. It can be very difficult to distinguish between damage from nematodes and fungal root diseases like *Rhizoctonia* or take-all. To test a paddock for the presence of nematodes it is important to follow recommended procedures. See section 1.9.2 above for information of soil sampling with PreDicta B. This includes taking a minimum number of soil samples from different locations in the paddock as well as at different soil depths. [80]

CCN

Soil sampling guidelines for RLN include:

- Using a soil corer or trowel to collect a soil sample to a depth of 0–10 cm.
- Taking samples in the crop rows, close to root systems.
- Sampling from 12 to 20 locations towards the margins of poor crop growth areas, taking a 500 g sample at each location.
- Sealing the soil in a plastic bag. [81]

Plant sampling guidelines for RLN include:

- Collecting plants from several locations at the margins of the impacted area, making sure to keep the root system intact.
- Sending a separate sample collected from a healthy area of the paddock for comparison.

76 GRDC (2016) Tips and tactics: Root-lesion nematodes. Northern region. Grains Research and Development Corporation, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

77 NSW DPI Understanding root lesion nematodes—a hidden problem. NSW Department of Primary Industries.

78 GRDC (2014) Managing crown rot. Grains Research and Development Corporation, June 2014, https://grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

79 M Williams (2016) Managing root lesion nematodes pre-sowing. Grains Research and Development Corporation, March 2016, https://grdc.com.au/Media-Centre/Media-News/West/2016/03/Managing-root-lesion-nematodes-presowing

80 NSW DPI Understanding root lesion nematodes—a hidden problem. NSW Department of Primary Industries.

81 M Williams (2016) Managing root lesion nematodes pre-sowing. Grains Research and Development Corporation, March 2016, https://grdc.com.au/Media-Centre/Media-News/West/2016/03/Managing-root-lesion-nematodes-presowing

- Including notes about paddock symptoms when sending in a sample for testing. [82]

1.10.2 Effects of cropping history on nematode status

Nematodes survive in the soil between crops and different tillage practices will affect their survival rates. Research has shown that nematode numbers may build up rapidly in wheat crops and decline slowly during fallow periods. When the soil is dry and no living roots are available, nematodes become dormant and may survive in the root tissue of old crops. RLN were able to survive in low numbers for eight years without a crop and build up to damaging numbers in the first wheat crop. After two wheat crops followed by 30 months without a host crop, RLN were still at levels that would reduce yield of intolerant wheat varieties. [83]

Planting resistant crops, is an effective management tool for reducing *P. thornei* populations. [84]

See Section 8: Nematode Control for more information.

1.11 Insect status of paddock

Damaging pests such as lucerne flea and wireworm can be particularly destructive in durum crops. Deciding the best way to sample for a particular pest depends on where in the crop the pest feeds and shelters, and the effects of weather on its behaviour. The stage of crop development and the insect being monitored, will determine which sampling method is most suitable. For example, pests in seedling crops generally cannot be collected by sweeping because the crop is too short.

Pest outbreaks occur often in response to natural conditions, but sometimes in response to management practices. Minimum tillage and stubble retention have resulted in greater diversity of invertebrate species seen in crops. Cultural control methods such as burning, rolling or cultivating stubbles are sometimes needed to complement chemical and biological controls. [85]

For more information, see Section 7, Insect control.

Beneficials

Beneficial insects and other invertebrates ("beneficials") offer a variety of ecosystem services that are essential within agricultural environments and it is important to conserve and promote them as far as is practical within the constraints of controlling for major crop pests. For example, many beneficial species act as pollinators or are important for soil health and nutrient cycling. Some beneficial invertebrates can also take the form of "natural enemies" of pest species and play a major role in the suppression of pest populations within our cropping systems. [86]

How to promote beneficials:

- Learn about beneficial insects and what they can do to help control your pests.
- Modify chemical use to preserve beneficial insects. Reduce use of broad-spectrum and other highly disruptive sprays, and spray only when economic thresholds are reached.
- Use targeted spray controls that are effective against the pest species, but limit the impact on beneficial insects (e.g. Bt sprays).
- Incorporate beneficial insect counts into crop monitoring program.

82 M Williams (2016) Managing root lesion nematodes pre-sowing. Grains Research and Development Corporation, March 2016, https://grdc.com.au/Media-Centre/Media-News/West/2016/03/Managing-root-lesion-nematodes-presowing

83 NSW DPI Understanding root lesion nematodes—a hidden problem. NSW Department of Primary Industries.

84 USQ (2015) Count your nematodes before planting wheat after mungbeans. University of Southern Queensland, March 2015, http://www.usq.edu.au/news-events/news/2015/03/kirsty-owen-mungbeans

85 P Bowden, P Umina, G McDonald (2014) Emerging insect pests. Grains Research and Development Corporation, July 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests

86 R Waugh (2011) Don't forget the good guys—recognising and identifying beneficial insects in your paddock. Grains Research and Development Corporation, September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54t/nax0b3j

- Investigate ways of encouraging beneficial insects, e.g. maintain host vegetation, release commercially available beneficial insects (e.g. to target whiteflys, mites, aphids and thrips), provide supplementary sources of nectar and pollen.
- Manipulate the behavior of beneficial insects with attractants or with plant structure or arrangement.
- Be prepared to tolerate some "below threshold" insect pest activity to allow for the persistence of beneficial insects. [87]

1.11.1 Insect sampling

Sampling methods should be applied in a consistent manner between paddocks and sampling occasions. Any differences can then be confidently attributed to changes in the insect populations, and not different sampling techniques.

fSoil sampling

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

Use a standard spade and take a minimum of one spade full of soil at 10 sites within the paddock. If pest numbers exceed the threshold in one sample, take another spade full within 5 m. [88]

The SARDI Entomology Unit provides an insect identification and advisory service. The service identifies insects to the highest taxonomic level for species where this is possible and can also give farmers biological information and guidelines for control. [89]

Insect ID: The Ute Guide

Figure 5: *GRDC's Ute Guide for insect identification is available as an app.*

Source: Grains Research and Development Corporation

The Insect ID Ute Guide is a comprehensive reference guide for insect pests commonly affecting broadacre crops and growers across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored and other pests that they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [90]

App features:

- region selection
- predictive search by common and scientific names

87 R Waugh (2011) Don't forget the good guys—recognising and identifying beneficial insects in your paddock. Grains Research and Development Corporation, September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54t/nax0b3j

88 DNRE (2000) Sampling methods for insects and mites. Department of Natural Resources & Environment Victoria, http://ipmguidelinesforgrains.com.au/insectopedia/introduction/sampling.htm

89 PIRSA (2015) Insect diagnostic service. Primary Industries and Regions SA, June 2015, http://pir.sa.gov.au/research/research_specialties/sustainable_systems/entomology/insect_diagnostic_service

90 GRDC. Apps. Grains Research and Development Corporation, https://grdc.com.au/Resources/Apps

- compare photos of insects side by side with insects in the app
- identify beneficial predators and parasites of insect pests
- opt to download content updates in-app to ensure you're aware of the latest pests affecting crops for each region
- ensure awareness of international bio-security pests.

Insect ID, The Ute Guide is available on Android and iPhone.

1.11.2 Effect of cropping history

It is important to consider paddock history when planning for pest management. Resident pests can be easier to predict by using paddock history and agronomic and weather data to determine the likely presence (and numbers) of certain pests within a paddock. This will point towards the likely pest issues and allow growers to implement preventive options. [91] Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil moisture retention, groundcover and soil biology and this has also affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity but also create more favourable conditions for many pests such as slugs, earwigs, weevils, beetles and many caterpillars. In turn they have also influenced beneficial species such as carabid and lady beetles, hoverflies and parasitic wasps. [92]

See Section 7: Insect control for more information

91 R Jennings (2015) Growers chase pest-control answers. Grains Research and Development Corporation, June 2015, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers

92 P Bowden, P Umina, G McDonald (2014) Emerging insect pests. Grains Research and Development Corporation, July 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests

Pre-planting

Key messages:

- Take the time to carefully choose a variety best suited to your goals and conditions.
- Consult the Australian Durum Growers Association and/or State crop variety sowing guides for most updated information on varietal characteristics.
- Good seedling establishment is more likely if seed is undamaged, stored correctly and from a plant that had adequate nutrition.
- The main factors that affect the viability or germ of the seed are moisture levels and temperature, so these factors should be considered in storing seed.
- The safest application method for high rates of high ammonium content fertilisers is to place them away from the seed by physical separation or by pre- or post-plant application by broadcasting onto the soil surface before seeding or in crop application after seeding.

2.1 Varietal performance and ratings yield

Seasonal, environmental and management conditions all influence durum wheat yield and quality, but often variety is the predominate influence (Photo 1). [1] The commercial release of several new durum varieties in South Australia (SA) has set a yield performance benchmark of up to ~10% above Tamaroi(Ɒ which was the previous standard. [2]

Photo 1: *Durum in the paddock.*

VIDEOS

WATCH: Over The Fence Revisited: Research investment pays dividends with new durum varieties

1 M Sissons, B Ovenden, D Adorada, A Milgate (2014). Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

2 GRDC (2012) Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DGA00001

Improved varietal choice and management options for existing and potential new durum growers within the Southern region has provided a viable alternative crop choice for grain growers. Durum has excellent rust resistance relative to most wheat varieties. This reduces the need for fungicides and the potential environmental risk issues associated with their use. In offering an alternative crop choice, durum may also provide break crop opportunities for diseases, such as cereal cyst nematode (though all varieties are moderately susceptible) and rusts. Susceptibility is defined as multiplying the disease and hence durum is not a good break crop for CCN although are better than some bread wheat varieties. [3]

Table 1 provides a comparison of the yield, quality, maturity and other characteristics of the most common durum varieties grown in the southern region. Table 2 lists the agronomic characteristics of some of these varieties.

Table 1: *Durum varietal performance and ratings yield.*

Variety	Yielding ability	Quality traits	Maturity	Other varietal traits	Coleoptile length (cm)
DBA-Aurora(D), 2014	Grain yield slightly lower than Yawa(D).	Improved grain size and lower screenings more similar to Hyperno(D) and Saintly(D).	Mid maturing.	Good disease resistance profile. Good early vigour and grass weed competitiveness.	7.5
Tjilkuri(D), 2010	Greater yields than Tamaroi(D).	Improved semolina colour.	Mid maturing; similar maturity to Tamaroi(D).	Similar adaptation and disease resistance profile to Tamaroi(D). A mid-season fully-awned variety. Tolerant to boron.	7.6
Saintly(D), 2008		High quality semolina with higher yellow pigment colour.	Early maturing line suited to both short and medium season production environments.	Awnless, earlier flowering than Kalka(D) and Tamaroi(D). Performed very well in dry finishing conditions in SA. Slightly less stem and leaf rust resistance compared to Hyperno(D). Australian Premium Durum (ADR) classification in SA. High levels of resistance to stem, stripe and leaf rust.	7.2
Hyperno(D), 2008	High yield potential.	Improved semolina colour and better sprouting and black point tolerance than Kalka(D) and Tamaroi(D).	Mid maturing; similar maturity to Kalka(D) and Tamaroi(D).	An awned mid-season white chaffed variety adapted to medium rainfall zones. Similar adaptation and disease resistance profile to Kalka(D) and Tamaroi(D). Intolerant of boron.	7.8

3 GRDC (2012) Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DGA00001

Variety	Yielding ability	Quality traits	Maturity	Other varietal traits	Coleoptile length (cm)
Caparoi(D), 2008	High yielding (similar to Jandaroi(D).	Good semolina colour, excellent physical grain quality and high grain protein. Grain quality is similar to EGA Jandaroi(D) and superior to Wollaroi(D).	Mid maturing; slightly earlier flowering than Tamaroi(D),	Semi-dwarf variety. High level of resistance to stem rust, stripe rust and yellow leaf spot. Moderately tolerant to root lesion nematodes. Good resistance to lodging and shattering. Strong seedling vigour, strong straw and shedding resistance.	7.5
WID802(D), 2012 (targeted for the south east of SA [Tatiara districts])	High yields.	Sometimes small grain size. may have low protein if nitrogen is limiting.	Early to mid maturing; similar maturity to Tamaroi(D).	Similar adaptation and disease resistance profile to Tamaroi(D). Likely to produce high screenings in short finishes.	7.7
Gundaroi(D), 1999 (adapted to SA environments)	Slightly better yielding than Yallaroi(D).	Pasta quality similar to Yallaroi(D) and Tamaroi(D).		Superior site adaptation in SA, with disease resistance characteristics of Yallaroi(D) and Tamaroi(D).	
Tamaroi(D), 1998 (adapted to SA environments)	Yields around 15% higher than Yallaroi(D	Higher protein levels than Wollaroi(D) and Yallaroi(D).	Quicker in maturity than Yallaroi(D).		7.9
Wollaroi(D), 1993		Grain protein content is about 0.5% higher than Yallaroi(D). Superior bright, clean yellow appearance.		Medium height. Strong straw with good lodging resistance.	7.2
Yallaroi(D), 1987	Consistently out-yields Kamilaroi(D).	Protein content may be lower than Kamilaroi(D). Excellent colour and dough strength		Excellent resistance to black point. Slightly less tolerant of weather damage than Kamilaroi(D).	
Kamilaroi(D), 1982		Good dough properties, high protein.		Good tolerances to all of the then current rust strains.	

Source: Department of Economic Development, Jobs, Transport and Resources

Table 2: *Agronomic guide to common durum varieties.*

	Maximum quality southern zone	Rainfall			Screenings	Maturity	Height	Lodging	Sprouting	Head type		Soil tolerance	
		Low <400 mm	Med 4–500 mm	High >500 mm						Colour	Awn	Boron	Acid
Caparoi(D)	ADR		✓			M	S–M	MR	M				I
DBA Aurora(D)	ADR		✓	✓	R	M	M	MR	MR	W	A	MT	
Hyperno(D)	ADR		✓			M	M	MR	MR	W	A	I	
Tjilkuri(D)	ADR				MS	M	M		S	W/B	A	T	
WID802(D)	ADR				MS	E–M			MR				

Source: Department of Economic Development, Jobs, Transport and Resources

IN FOCUS

DBA-Aurora(D)

Durum production in Australia has halved since 2002. With reasons for the decline including unfavourable seasons, disease, and lower prices, the University of Adelaide released a new durum wheat variety called DBA-Aurora(D) which promises a step-change in potential durum production in southern Australia (Photo 2). DBA-Aurora(D) heralds a new beginning for the Australian durum industry with many superior attributes over current commercial grown varieties including Hyperno(D), Saintly(D), Tjilkuri(D), Yawa(D) and WID802(D) in the southern region (SA and Victoria). Its most notable features are an improved disease resistance package, larger grain size, good test weight, early vigour and weed competiveness when compared to the other high yielding durum varieties. DBA-Aurora(D) is a more robust durum that is better suited to an integrated weed management system, and less likely to be downgraded for small grain under a tight spring finish with minimal rainfall. [4]

Photo 2: *Dr Jason Able, from the University of Adelaide, led the durum breeding program to develop the durum wheat variety DBA-Aurora(D).*

Source: Grains Research and Development Corporation

VIDEOS

WATCH: GCTV Extension files: NVT Durum performances SA 2014.

2.1.1 Durum variety yield performance update

Across the six central region durum National Variety Trials (NVT) sites in South Australia in 2015, average site yields were 2.17 t/ha (Table 3). These yields are 23–33% below the bread wheat site averages in the SA's Mid North and Yorke Peninsula sites respectively, clearly demonstrating the lower tolerance in durum to difficult weather conditions for crop growth in 2015. [5]

4 AEGIC (2014) New dawn for pasta wheat in Australia. Australian Export Grains Innovation Centre, October 2014, http://newsite.aegic.org.au/media/news/2014/10/new-dawn-for-pasta-wheat-in-australia.aspx

5 R Wheeler (2016) Wheat variety research update for 2016. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Wheat-variety-research-update-for-2016

Table 3: *Mean grain yield (%) from 2015 NVT in SA's Yorke Peninsula and Mid North agricultural regions. Yield expressed as a function (%) of trial mean yield is shown for each region.*

	SA agricultural region	
Variety	**Yorke Peninsula**	**Mid North**
Caparoi(D)	93	96
DBA-Aurora(D)	114	110
Hyperno(D)	96	96
Saintly(D)	115	114
Tamaroi(D)	109	99
Tjilkuri(D)	84	80
WID802(D)	101	100
Yawa(D)	96	101
Site mean (t/ha)	2.06	2.29

Source: Grains Research and Development Corporation

Saintly(D) produced the highest average yields of 2.49 t/ha across all Mid North and Yorke Peninsula trials, but was closely matched by DBA Aurora(D) which produced 2.44 t/ha. At only one site, Paskeville, did Saintly(D) significantly out-yield DBA Aurora(D). All other durum varieties trialled were significantly lower yielding, and surprisingly the formerly high yielding variety Yawa(D), produced very moderate yields in 2015. These results are very encouraging for growers currently adopting the new variety DBA Aurora(D), and when combined with improved grain quality will show the improvements made over Yawa(D) in recent years. [6]

The long term predicted yield of durum wheat in Victoria's Wimmera region is shown in Table 4. The long term yield prediction has been produced using the NVT Long Term MET (Multi Environment Trial) analysis. The analysis produces predictions or "Production Values" for every variety in every NVT trial across all years identified within the dataset. [7]

Table 4: *Long term predicted yield (2011-2015) of durum wheat in Victoria's Wimmera region, expressed as a percentage of the mean yield. Number of sites years in brackets.*

Mean yield (t/ha)	**3.76**
Caparoi(D)	107 (4)
DBA-Aurora(D)	109 (4)
EGA Bellaroi(D)	96 (4)
Hyperno(D)	107 (4)
Saintly(D)	113 (4)
Tjilkuri(D)	107 (4)
WID802(D)	108 (4)
Yawa(D)	117 (4)

Source: Department of Economic Development, Jobs, Transport and Resources

6 R Wheeler (2016) Wheat variety research update for 2016. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Wheat-variety-research-update-for-2016

7 DEDJTR (2016) Victorian winter crop summary 2016. Department of Economic Development, Jobs, Transport and Resources, http://www.nvtonline.com.au/wp-content/uploads/2016/03/NVT-Victoria-Winter-Crop-Summary-2016_for-web.pdf

2.1.2 Varietal maturity

There is currently a relatively small range in maturity length in durum varieties compared with bread wheat varieties. Durum wheats are generally similar in maturity to the quickest bread wheat varieties. This is an important consideration when managing frost risk and can limit opportunities to exploit early planting opportunities. Extended flowering could reduce the risk of pollination failure caused by frost or extended moist weather. Durum is also more sensitive to very cold conditions (near frost conditions) during flowering than bread wheat. The time difference in reaching full maturity between the early flowering and late flowering tillers is normally fairly small; therefore, the early heads are not likely to be ripe for many days ahead of the later heads. Harvesting should not be delayed significantly. Durum wheats will perform well if sown later, but grain yields will depend on seasonal conditions, especially during the flowering and grain filling stages. [8]

Varietal maturity is important to take into consideration when deciding when to sow (Photo 3).

Photo 3: *These cereal plots show the differences in maturity of varieties grown in trials at Inverleigh, Victoria, in 2013. The plots were all sown on 10 May but maturity ranged from ear emergence (GS51) to milk development (GS71) in October.*

Source: Grains Research and Development Corporation

2.2 Planting seed quality

Good seedling establishment is more likely if seed is undamaged, stored correctly and from a plant that had adequate nutrition. Early seedling growth relies on stored energy reserves in the seed. 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.

Heat damage causes slower germination, delayed emergence of the primary leaf, stunted growth or termination of the germination process. In severe cases, seed death may occur (Photo 4). During bulk storage, areas of excessive moisture can lead to microbial-induced “hot spots” and since moisture moves from hot to cooler areas, further local heating is caused, setting off a chain reaction. [9]

8 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

9 Hatting H. (2012). Factors affecting wheat seed germination. http://www.grainsa.co.za/factors-affecting-wheat-seed-germination

MORE INFORMATION

GRDC Retaining seed factsheet

Photo 4: *Normal seed (left) compared to heat-damaged seed (right). Note the distinct colour difference.*

Source: Grain SA

2.2.1 Seed size

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

Durum seed is, on average, 20% larger than bread wheat seed. The planting rate should be adjusted based on 1000 grain weight data to sow 160-180 seeds/m^2. However, a higher planting rate may be beneficial in some situations (e.g. seed with a low germination, irrigated crops or early/late sowings). Conventional sowing equipment can be used but the larger seed size may necessitate adjustments.

> *In the Southern region, seeding at a lower rate (e.g. 100 seeds/m^2) could leave a durum crop at risk of being overrun with ryegrass, due to durum's lesser competitive ability against weeds.*

Agronomist's view

The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface (Photo 5). Coleoptile length is an important characteristic to consider when planting a wheat crop, especially in drier seasons when sowing deep to reach soil moisture. For 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, as the shoot will emerge from the coleoptile underground and it may never reach the soil surface. [10]

Durum varieties have a much narrower spread in coleoptile length than bread wheat varieties. Seed source is a more important determinant of coleoptile length in durum wheats than variety.

10 J Pumpa, P Martin, F McCrae, N Coombes (2013) Coleoptile length of wheat varieties. NSW Department of Primary Industries, Februuary 2013, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/459006/Coleoptile-length-of-wheat-varieties.pdf

Photo 5: *The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface.*

Photo: Nicole Baxter, Source: GRDC

Small seeds contain less starch reserves than larger seeds. Starch is a form of energy for seeds, so less starch means less energy to get the seedling out of the ground. It also means less energy to fight off seedling stresses such as disease, waterlogging or false breaks.

Small seed—for example, 1,000 seed weight of less than 30 g—should not be sown deep, and should only be sown where there is ideal moisture. Increase sowing rates by 10–15% to compensate for potentially low vigour. [11]

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, in order to see what affect it may have on coleoptile length. [12]

2.2.2 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

11 K Condon K (2003) Targeting optimum plant numbers. NSW Agriculture, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/168523/targeting-optimum-plant-numbers.pdf

12 J Pumpa, P Martin, F McCrae, N Coombes (2013) Coleoptile length of wheat varieties. NSW Department of Primary Industries, February 2013, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/coleoptile-length

- visible germination. [13]

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.

Use sound seed that is true to type (varietal purity), free of diseased seed and weed seeds, cracked and small grain, and barley and bread wheat grain. Ensure that the initial seed of a purchased variety is of high quality, from certified seed stocks, with a germination percentage >85%. Before harvesting seed stocks for the following season, rogue all off-types and contaminant crop and weed plants.

Seed grain kept for sowing in subsequent seasons must be stored in clean silos capable of aeration, sealing for insect control and keeping grain dry and as cool as possible. Such storage conditions will assist the maintenance of high viability seed for the following season. Treat seed with an appropriately registered product just prior to sowing to control smut and bunt. Some chemical constituents can reduce viability and seedling vigour if they remain in contact with the seed for any length of time. Ground preparation is the same as for bread wheat. Spraying to eliminate all volunteer plants of bread wheat, barley and other crop/weed species needs to be carried out . [14]

CropCare have launched a new product, Pontiac®, which is registered to provide broad spectrum control of seed and two soilborne fungi in cereals as well as control of aphids and other stored grain insect pests through the combination of flutriafol, metalaxyl-m and imidacloprid.

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, see Australia Seeds Authority Ltd.

While 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 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 (Photo 6). Cover with a little more sand/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. [15]

13 J Pumpa, P Martin, F McCrae, N Coombes (2013) Coleoptile length of wheat varieties. NSW Department of Primary Industries, February 2013, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/459006/Coleoptile-length-of-wheat-varieties.pdf

14 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

15 GRDC (2011) Retaining seed. Saving weather damaged grain for seed, northern and southern regions. GRDC Fact Sheet Jan. 2011, http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC_FS_RetainingSeed2.pdf

MORE INFORMATION

Germination testing and seed rate calculation

Grain retained for seed from a wet harvest is more likely to be infected with seed-borne disease. It is also more likely to suffer physical damage during handling, increasing the potential for disease. Seed-borne disease generally cannot be identified from visual inspection, so requires laboratory testing. [16]

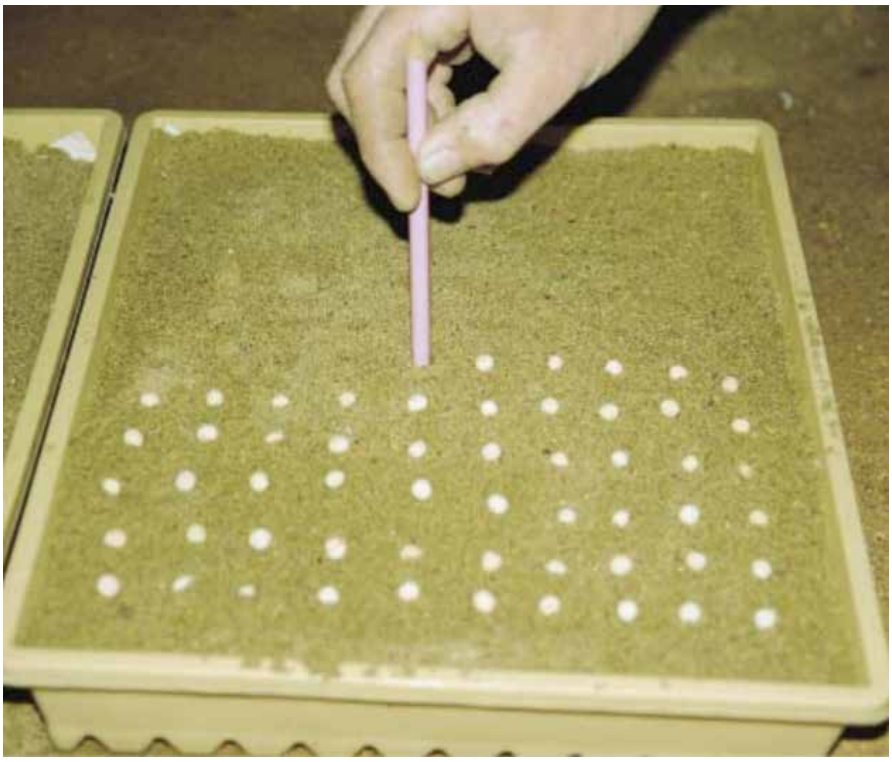


Photo 6: *Use a pencil or straw to poke holes in a testing tray.*

Source: NSW DPI

2.2.3 Seed storage

The aim of storage is to preserve the viability of the seed for future sowing and maintain its quality for market. Proper storage of any seed begins with the sanitation of storage facilities and reducing or eliminating the respiration of the seed. The main factors that affect the viability or germ of the seed are moisture levels and temperature. [17] By decreasing both factors, the longevity of the seed will increase.

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 respires. The ideal storage conditions are listed below:

- Temperature <15°C. High temperatures can quickly reduce seed germination and quality. This is why germination and vigour testing prior to planting are 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 head space may condense and fall back as free water, causing a ring of seed to germinate against the silo wall.
- Aeration slows the rate of deterioration of seed with 12.5–14% moisture. Aeration markedly reduces grain temperature and evens out temperature differences that cause moisture movement.

16 GRDC (2011) Retaining seed. Saving weather damaged grain for seed, northern and southern regions. GRDC Fact Sheet Jan. 2011, http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC_FS_RetainingSeed2.pdf

17 EH Roberts (1960) The viability of cereal seed in relation to temperature and moisture. Annals of Botany, 24, 12–31, http://aob.oxfordjournals.org/content/24/1/12.abstract

VIDEOS

WATCH : Over the Fence: Insure seed viability with aerated storage.

- No pests. Temperature <15°C stops all major grain insect pests from breeding, slowing down their activity and causing less damage. [18]

Living organisms—insects, rodents, fungi

Insects, rodents and fungi will infest stored seed and can cause a reduction in quality and quantity. Insect feeding can decrease your grain amount by up to 10%. Bait or insecticide should be set around storage areas to limit these pests.

Temperature

Maintaining stored seed at cool temperatures is of great importance. When seed must be dried down, do not dry seed above 32°C and do not maintain elevated temperatures any longer than is required to reach 10–12% seed moisture content. When temperatures reach 5–10°C, insects will begin to develop and reproduce.

Humidity

Humidity should remain in the 20-60% range . Above this, seeds will rapidly gain water increasing the potential to reduce germ levels. In general, for most plant species, seed will maintain its viability and vigour when the sum of air temperature in degrees Fahrenheit and percent relative humidity of the air is 100 or less.

Seed moisture

Seed moisture should remain below 12% during storage to maintain germination of wheat seed. Under cooler temperatures, grain can be stored at slightly higher moisture contents. Table 5 summarises the effect of various moisture contents on seed viability. [19]

Table 5: *Effects of different levels of moisture in seeds.*

Seed moisture content	Condition
4–8%	Little or no insect activity (too dry for most insects).
10–12%	Satisfactory to store most seeds in open storage and in cloth bags or moisture-resistant containers.
14–16%	Molds (fungi) may grow on and in seeds in open storage and on seeds in cloth bags or sealed containers. Harmful to seeds of many plant kinds.
18–20%	Seed may heat because of seed respiration and microbial activity. Seed declines rapidly in viability and vigor.
24–60%	Seeds may rot.

Source: Syngenta

For more information, see Section 13: Storage.

2.2.4 Safe rates of fertiliser sown with the seed

Crop species differ in tolerance to nitrogen (N) fertiliser when applied with the seed at sowing. The safest application method for high rates of high ammonium content fertilisers is to place them away from the seed by physical separation (combined N–phosphorus products) or by pre or post-plant application (straight N products). For the lower ammonium content fertilisers, e.g. mono-ammonium phosphate (MAP), close adherence to the safe rate limits set for the crop species and the soil type is advised. 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, then it should be applied pre-planting or applied at planting but not in contact with the seed (i.e.

18 GRDC (2011) Retaining seed. Saving weather damaged grain for seed, northern and southern regions. GRDC Fact Sheet Jan. 2011, http://storedgrain.com.au/wp-content/uploads/2013/06/GRDC_FS_RetainingSeed2.pdf

19 Syngenta (2012) Storing treated certified seed: cereals. Technical bulletin. Syngenta Crop Protection, http://www.syngentacropprotection.com/assets/assetlibrary/treatedseedsnov23c.pdf

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. N rates should be significantly reduced 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. [20]

20 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

Planting

Key messages

- Use seed that has a high germination rate, is large and plump, is genetically pure, and is free of contaminants such as weed seeds and impurities of other winter cereals, in particular bread wheat and barley.
- Durum yield potential can be influenced by sowing date and variety choice.
- Highest yields are achieved from current durum varieties when sown early to mid season.
- If seeding is delayed, sowing varieties with larger grain size (i.e. Caparoi(D), Saintly(D)) may reduce screenings risk
- Aim for a seeding rate of 220 seeds/m^2 to maximise yield and quality.
- Sowing depth should be about 3–5 cm and not exceed 8 cm, as current durum cultivars are semi-dwarf with reduced coleoptile length which cannot penetrate greater soil depths. [1]

3.1 Inoculation

Not required for this crop.

3.2 Seed treatments

Durum seed should be treated to control bunt, flag and loose smut. These diseases generally occur at low or trace levels but, in the absence of seed treatments, they have the potential to increase rapidly causing significant economic losses to growers. Where farmers decide not to treat seed for one year, they are advised to treat the following year. Bunt smut spores are spread from infected heads onto healthy seed during harvest. Loose smut spores spread in the wind at flowering time and infect developing embryos. Loose smut infection remains hidden inside the seed and so is more resistant to seed treatments than the surface borne bunt and covered smuts. Flag smut spores spread by wind from infected leaves and infect developing heads. They can also survive in soil for several years infecting subsequent crops. Where smut infection is observed, growers are advised to buy new seed and use the full rate of registered seed treatments. Ensure that any machinery that has been in contact with the diseased seed is cleaned. The accepted tolerance levels are nil for bunt and three infected pieces in half a litre of grain for loose smut. Any wheat exceeding these limits will not be accepted. There is a nil tolerance level for any smutted barley or oat grain. [2]

Quality seed for planting is essential. Only use seed that has a high germination rate and vigour, is large and plump, is genetically pure, and is free of all contaminants such as weed seeds and impurities of other winter cereals, in particular bread wheat and barley. 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.

1 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

2 SARDI (2017) Cereal Seed Treatments 2017 http://pir.sa.gov.au/__data/assets/pdf_file/0005/237920/cerealseedtreat2017_web.pdf

With the recent spread of Russian wheat aphid through parts of the Southern Cropping region, growers should keep an eye out for recommendations for the application of Imidacloprid when cereals (including durum) are sown early in the sowing period.

MORE INFORMATION

APVMA

Agronomist's view

The economic benefits of this kind of treatment have previously been questioned, but with the price of Imidacloprid seed treatments dropping, and the expansion of potentially threatening aphids, seed treatments are an important first step in protecting crops. [3]

CropCare has launched a new product, Pontiac®, which is registered to provide broad spectrum control of seed and two soilborne fungi in cereals as well as control of aphids and other stored grain insect pests through the combination of flutriafol, metalaxyl-m and imidacloprid. [4]

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

- slowing the rate of germination, or
- 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).

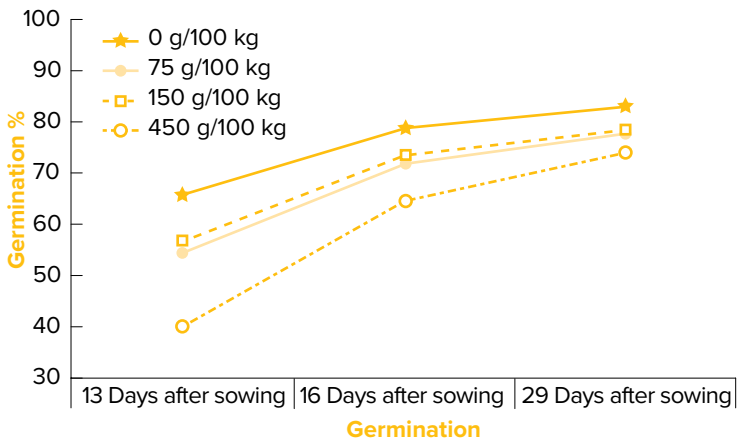


Figure 1: *Impact of seed-treatment fungicide on the rate of germination.*

Source: based on P Cornish 1986

MORE INFORMATION

Cereal seed treatments 2016

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. [5]

3 Tony Craddock (2016). Personal Communication.

4 SARDI (2017) Cereal Seed Treatments 2017 http://pir.sa.gov.au/__data/assets/pdf_file/0005/237920/cerealseedtreat2017_web.pdf

5 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

MORE INFORMATION

GRDC Targeted nutrition at sowing Factsheet

3.2.1 Fertiliser at seeding

The amount of nitrogen safely placed with the seed will vary depending on soil texture, amount of seedbed utilisation and moisture conditions. Higher amounts of nitrogen can be safely applied with the seed if it is a polymerised form of urea where the nitrogen is released over the period of several weeks. If soil moisture is marginal for germination, high rates of fertiliser should not be placed with the seed. Both nitrogen and phosphorous can be banded prior to seeding, but take care to avoid loss of seedbed moisture and protective crop residue. Place phosphorous with or near the seed at seeding time or band prior to seeding. [6]

3.3 Time of sowing

Time of sowing is a critical factor in crop risk management. The optimal sowing time for durum is a compromise. Changes in sowing date and/or sowing location can dramatically affect development through the varying thermo-photoperiodic conditions that they create. [7] Sowing too early increases the risk of frost damage and haying-off, while sowing too late increases the chance of grain filling during increasingly hot and dry conditions. [8] Growers should aim to minimise the combined risks of frost damage or moisture stress around flowering/grain filling, and rain or storm damage just prior to harvest. None of these risks can be eliminated, but minimisation is possible. The optimum sowing date will depend on the maturity rank of the variety, latitude of the sowing site and topographic aspect (e.g. north/south facing slope, elevation).

Durum yield potential is influenced by sowing date. Durum wheats can perform well when sown later, but grain yields will depend on seasonal conditions, especially during the flowering and grainfilling stages. Three years of trials by the Grains Research and Development Corporation have shown that varietal yield rankings change with sowing dates (Table 1). The new durum varieties expressed their improved yield potential to the greatest degree at early to mid-season sowing dates, and yield differences among varieties are less pronounced with late sowing, irrespective of seasonal conditions. Varieties with higher yield potential, such as Yawa(Ɒ, WID802(Ɒ, and Hyperno(Ɒ, are favoured most by early sowing (1–15 May). At later sowing, yield differences among new varieties are negligible, but screenings have been more prominent. Therefore, larger grained varieties such as Caparoi(Ɒ, Tjilkuri(Ɒ, Saintly(Ɒ and Aurora(Ɒ are preferred if sowing is delayed because they are less likely to be downgraded from small grain screenings. [9] Varieties with smaller grain size should be avoided if sowing is delayed. [10]

6 Alberta Agriculture and Forestry (2016) Fall Rye Production. Alberta Government, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

7 F Giunta, R Motzo, A Virdis (2001) Development of durum wheat and triticale cultivars as affected by thermo-photoperiodic conditions, Australian Journal of Agricultural Research 52(3) 387-396, http://www.publish.csiro.au/paper/AR00034

8 PIRSA. Impact of dry sowing, frost, crop type and variety. http://pir.sa.gov.au/__data/assets/word_doc/0005/241583/Impact_of_dry_sow,_frost,_crop_type_and_variety.doc

9 GRDC (2015) Final Report – Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, March 2015, http://finalreports.grdc.com.au/DGA00001

10 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

Table 1: *Effect of sowing date on durum varietal yield performance in trial area.*

Variety	Early sown (May 1–15)	Mid sown (May 15–June 5)	Late sown (after June 15)
Caparoi(D)	98	95	103
Saintly(D)	107	107	105
Tjilkuri(D)	113	108	107
WID802(D)	117	112	106
Hyperno(D)	120	109	106
Yawa(D)	123	118	106
Tamaroi(D)	100	100	100
Tamaroi(D) avg yield	4.44 t/ha	4.60 t/ha	4.31 t/ha

Source: Grains Research and Development Corporation

VIDEOS

WATCH: GCTV Extension Files: Early sowing opportunities

WATCH : Over the Fence South: Early sowing protects crops from winter wet.

3.3.1 Early / dry Sowing

Early sowing helps maximise yield and minimises the likelihood of quality downgrades due to high screenings levels. [11]

Crop growth and haying-off risks with early sowing

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 for grains to fill later in the season. Strong early growth provides more heads and more potential grains in each head.

Very early sowing of an early maturing variety with little or no vernalisation requirement and relatively insensitive to day length (for example, Axe(D)) will cause rapid development. The lack of biomass at flowering will reduce the numbers 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.

The 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 delaying sowing in the Victorian Mallee from 1 May to 1 June caused an average two per cent yield loss. In two of these years the yield loss was 0.5 tonnes per hectare. Similar results have been seen in trials across the southern region (Figure 2). 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 nitrogen are applied upfront in early-sown crops, growth before flowering can be excessive. If moisture is limited during grain fill, the canopy will have limited capacity to fill all grains, leading to higher screenings and lower yields – even in the absence of frosts.

Frost risk of early sowing

The main risk of early sowing is frost between flowering and early grain fill. 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 – as their cold requirement delays flowering.

Sowing time effect on disease

Foliar diseases

Earlier sowing tends to increase the severity of yellow leaf spot, Septoria tritici blotch and barley yellow dwarf virus (BYDV). Wheat streak mosaic virus (WSMV) and BYDV can also be worse with early sowing however, for BYDV it depends on timing of

11 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

the aphid flight. Warmer temperatures in early autumn favour wheat curl mite that transmit WSMV. Delaying sowing is not a useful tool to aid stripe rust control as 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 start working at a later growth stage.

Root diseases

Growers can identify the risk of significant soil-borne 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 grain fill. 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. [12]

Earlier sowing results in a greater number of tillers that survive to produce a head (Figure 2). With winter wheat and some spring cultivars, earlier sowing results in more leaves prior to first node stage (GS31), and since each leaf has a tiller bud, the crop has more time to grow tillers before the appropriate development stimuli signal (vernalisation, day length and temperature) for the crop to enter stem elongation. Generally, with spring wheats (including durum) the cultivar's sowing date has less influence on tiller number since leaf number and resultant tiller number is more predetermined (the crop has less requirement for vernalisation prior to stem elongation). However, tillers from early sowings of spring cultivars have longer to grow and as a consequence their survival to produce a head is usually greater from early sowings. [13]

12 GRDC (2011). Time of Sowing. Impact on yield and quality of wheat. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/03/time-of-sowing

13 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

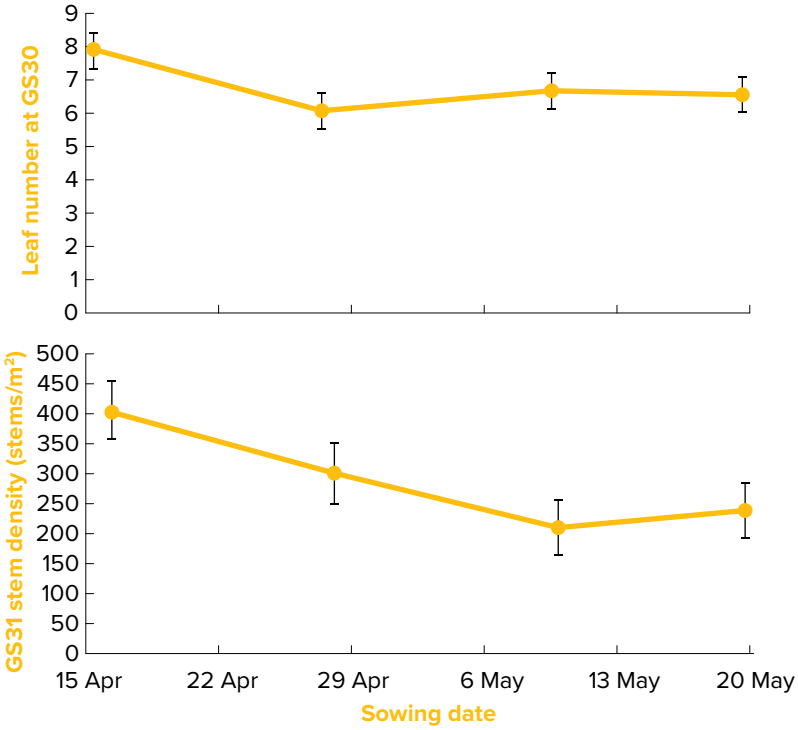


Figure 2: *Influence of sowing date on leaf number at the start of stem elongation (GS30; top graph) and tiller number at first node (GS31; bottom graph) – Temora, NSW (Hunt et al 2011).*

Source: Grains Research and Development Corporation

Spread the risk:

- Don't commit your whole cropping program to any one seeding option.
- Not all paddocks are suitable for very early seeding.
- Soil type, surface cover and weed burden all need to be considered.
- Reduce the risk of frost damage by seeding higher elevated paddocks first. [14]

Dry seeding can:

- reduce seeding time when rain occurs
- maximise the length of growing season available to crops
- limit the yield reduction due to a late break to the season
- minimise the impact of delays due to excess rainfall
- reduce the amount of seeding and stress once the break occurs
- maximise efficiency of machinery and labour.

Dry seeding is generally most successful:

- in light soils
- when the soil is very dry (not patchy or marginal)
- where there is a low weed burden, or a low-cost control strategy is available
- where wind erosion risk is low.

14 PIRSA (2003). Impact of dry sowing, frost, crop type and variety. http://pir.sa.gov.au/__data/assets/word_doc/0005/241583/Impact_of_dry_sow,_frost,_crop_type_and_variety.doc

MORE INFORMATION

GRDC Time of Sowing Factsheet – Southern Region.

VIDEOS

WATCH : GCTV Extension files: Wheat sowing strategies.

WATCH : GCTV15: Optimal flowering – follow up.

If there there are high levels of brome grass or herbicide resistant ryegrass present it can result in major weed blow outs!

Agronomist's view

Dry seeding can be hard on equipment due to hard, dry soils and dust.

Dry seeding works best where:

- paddocks or soils –
- will be seeded no matter when the season breaks
- have low, or controllable, weed burdens
- won't erode or fill in furrows (which can result in excess soil cover and poor emergence)
- have low levels of disease and few soil-living mites and insects.
- there is sub-soil moisture
- low nitrogen rates can be used safely
- soils will provide good seed-to-soil contact without the risk of excessive soil throw or herbicide damage
- crops are sown that don't require the use of highly soluble post-sowing pre-emergent herbicides that could cause crop injury if applied to dry soils.

Risks from dry seeding include:

- wind erosion
- inability to easily or cheaply control weeds
- seedling death due to multiple small falls of rain after germination
- fertiliser toxicity
- lack of subsoil moisture to produce economic yields
- input costs are committed whether or not the rain arrives
- the growing season does not suit the dry-seeded crop
- diseases
- insects
- poor crop establishment due to seeding depth, poor seed-to-soil contact or herbicide damage [15]

3.4 Target plant populations

Aim for a seeding rate of at least 220 seeds/m^2 in medium to higher rainfall areas to maximise yield and quality.

Plant population, determined by seeding rate and establishment percentage, can be an important determinant of tiller density and, at a later stage, head density. High yields are possible from a wide range of plant populations, 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.

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

- sowing date – higher rates with later sowings
- seed germination and vigour percentage
- seed size

15 PIRSA (2003). Impact of dry sowing, frost, crop type and variety. http://pir.sa.gov.au/__data/assets/word_doc/0005/241583/Impact_of_dry_sow,_frost,_crop_type_and_variety.doc

- seedbed conditions
- tillage, e.g. no-till
- double-cropping
- soil fertility
- soil type
- field losses [16]
- soil moisture and seasonal outlook
- weed seed burden – use higher sowing rates for increased plant competition, e.g. if combatting herbicide resistant ryegrass populations.

Guidelines for durum

Chances of optimal yields are improved by establishing at least 160 – 200 plants/m^2 even in seasons of low rainfall. With irrigation, high-yielding dryland conditions or very early and very late plantings, populations of at least 1,000,000 plants/ha are recommended. Plant populations below this rate may result in a reduction in yield and increased weed competition. [17] An establishment figure of 70% means that for every 10 seeds planted, only seven will emerge to produce a plant. Planting rate to achieve 160 – 200 plants/m^2 is normally in the range of 100-110 kg/ha. [18]

3.5 Calculating seed requirements – sowing rate

Sowing rate can be considered a risk-management tool. Dense stands of plants tend to produce fewer tillers per plant (i.e. the primary and a few secondary), whereas stands at a reduced density have plants that produce a larger number of tillers per plant. These reduced-density stands have greater flexibility in response to changing growing conditions. For example, if moisture is limiting, fewer tillers are initiated; however, if seasonal conditions improve, additional tillers may develop. [19]

A sowing rate of 100-110 kg/ha is given as a general guide. However, growers may consider a variation, higher or lower, to benefit their situation. A reduced germination percentage or a late sowing will make it necessary to increase this rate. [20] Current advice is that seeding rates should be maintained at 200 seeds/m^2 to maximise yield and quality in all varieties across the Southern Australian durum growing environments. [21]

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

The following formula (Figure 3) can be used to calculate sowing rates, taking into account:

- target plant density
- germination percentage

16 NSW DPI (2008) Wheat growth and development – PROCROP Series.NSW Department of Primary Industries, February 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/516185/Procrop-wheat-growth-and-development.pdf

17 DAFQ (2012) Wheat – planting information. Department of Agriculture and Fisheries Queensland, 1 August 2012, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/planting-information

18 Tony Craddock. (2016). Personal communication.

19 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi() – Primefact 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

20 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi() – Primefact 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

21 GRDC (2015) Final Report – Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, March 2015, http://finalreports.grdc.com.au/DGA00001

- seed size
- establishment, usually 80%, unless sowing into adverse conditions

To calculate 1000 seed weight:

- count out 200 seeds
- weigh to at least 0.1 g
- multiply weight (g) by 5 [22]

Example

1000 seed weight (grams)		target plant population (/m²)		establishment % X germination %
35	X	140	X 100 ÷	80 X 90

= Your seedling rate 68 kg/ha

Your calculation

1000 seed weight (grams)		target plant population (/m²)		establishment % X germination %
_____	X	_____	X 100 ÷	_____

= Your seedling rate _____ kg/ha

Figure 3: *Seeding rate calculator.*

3.6 Sowing depth

For wheat seed to emerge successfully from the soil, the seed should never be planted deeper than the coleoptile length. The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface (Photo 1).

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

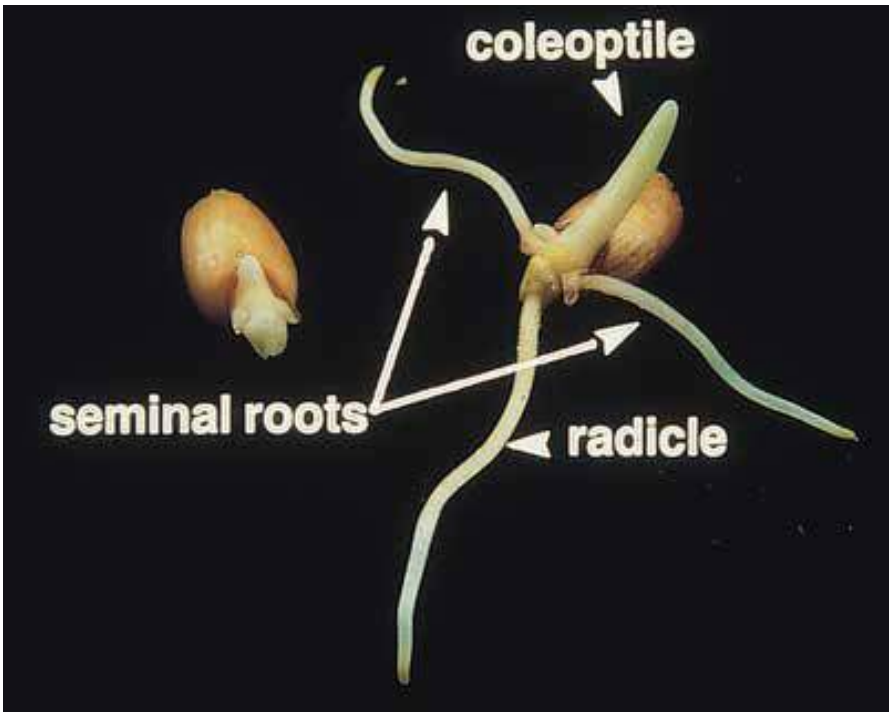


Photo 1: *The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface.*

Photo: David L. Hansen

While durum varieties have a narrow range in coleoptile lengths, this is an important characteristic to consider when planting a wheat crop, especially in drier seasons when sowing deep to reach soil moisture. Sowing varieties with short coleoptile lengths too deep can cause poor establishment, as the shoot will emerge from the coleoptile underground and it may never reach the soil surface (Photo 2). [23]

In a cultivated or chemically well-prepared seedbed, the sowing depth should be about 3–5 cm and not exceed 6 cm.

It is important to consult local information for the most effective sowing dates, rates and depths.

23 J Pumpa, P Martin, F McCrae, N Coombes (2013) Coleoptile length of wheat varieties. NSW Department of Primary Industries, Februuary 2013, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/459006/Coleoptile-length-of-wheat-varieties.pdf

Photo 2: *The difference in emergence and development between wheat sown at 30 to 35 mm and too deep and too shallow.*

Source: Grains Research and Development Corporation

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 while it is still below the soil surface. As 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. [24] Smilarly, emergence and vigour can be reduced with shallow sowing where impacts such as dry soil and herbicide residues can be involved (Photo 2).

For more information, see Section 4: Plant growth and physiology.

3.7 Sowing equipment

As much as 60% of the final yield potential for a 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. [25]

Seeder calibration is important for precise seed placement and seeders need to be checked regularly during sowing (Photo 3).

Conventional sowing equipment can be used for sowing durum seed, but the larger grain size of durum may necessitate appropriate adjustments. [26] Preferably use minimum disturbance equipment with a press wheel adjusted to soil and moisture conditions. [27]

Most growers in the Southern Region use either a knife-point/press-wheel tyne system or a single disc. Disc seeders can handle greater quantities of stubble but can experience crop damage issues with pre-emergent herbicide use. Tyne seeding

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

25 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

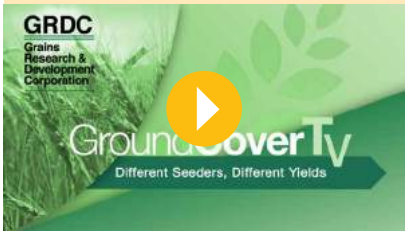
26 DAFQ (2012) Durum wheat in Queensland. Department of Agriculture and Fisheries Queensland, 26 June 2012, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

27 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

VIDEOS

WATCH : SFS seeder trial.

WATCH : GCTV19: Different seeders different yields. Local R&D – valuable solutions for the HRZ grain growers.



systems do not have the same herbicide safety issues but usually require some form of post-harvest stubble treatment, such as mulching or burning.

Photo 3: *Seeder calibration is important for precise seed placement and seeders need to be checked regularly during sowing.*

Photo: Rohan Rainbow

Plant growth and physiology

Key messages

- Crop growth stages need to be considered carefully to maximise yield and to ensure the appropriate timing for in crop treatments such as growth regulants, herbicides, fertilisers and insecticides.
- Genetics, planting practices and environmental factors will affect durum differently at different growth stages.
- High nitrogen is required for plant growth and to ensure durum reaches 13% protein levels.
- Durum is relatively sensitive to saline soils.
- Take time to learn and understand growth stage keys to make informed decisions and to be able to communicate about your crop.

4.1 Germination and emergence

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 Section 4.3.1 Zadoks Cereal Growth Stage Key, below, for more details.

Phase 1 of cereal growth starts when the seed begins to absorb moisture. Generally, a wheat seed needs to reach a moisture content of 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, consequently, 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 visibly grow. The radicle emerges, followed soon after by other primary roots and the coleoptile. The enzymes produced in Phase 2 mobilise sugars and amino acids stored in the seed and enable their transfer to the growing embryo. [1]

Emergence (GS07)

As the first primary roots appear, the coleoptile bursts through the seed coat and begins pushing towards the surface (Photo 1). Emergence is when the coleoptile or the first leaf becomes visible above the soil surface.

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

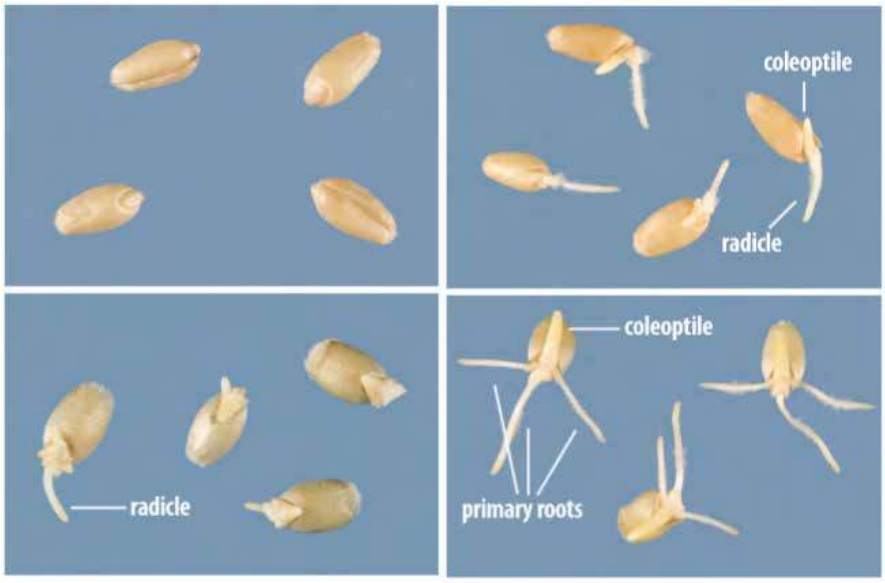


Photo 1: *Germinating wheat seed (with stages progressing from top left, bottom left, top right, bottom right). The radicle emerges followed by the coleoptile and the primary roots.*

Photo: L Turton, Source: NSW DPI

4.1.1 Factors affecting germination and emergence

Temperature

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.

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 between 10°C and 15°C. This is one reason why there is variation in emergence and establishment in the different wheat growing areas.

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. 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 fall of rain that keeps the soil moist for a few days before drying out. When the next fall of rain comes, the seed resumes germinating, taking up water and moving quickly through Phase 2.

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. Coleoptile length of durum wheat varieties is shown in Table 1. In some crusting soils, gypsum and/or lime may improve soil structure and assist seedling emergence. [2]

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

Table 1: *Predicted mean coleoptile length for durum wheat varieties at 18 National Variety Trials sites across Australia from 2010–2014.*

Variety	Predicted mean coleoptile length (cm)
Caparoi(D)	7.5
DBA_Aurora(D)	7.5
EGA_Bellaroi(D)	7.7
Hyperno(D)	7.8
Jandaroi(D)	7.0
Kalka(D)	7.4
Saintly(D)	7.2
Tamaroi(D)	7.9
Tjilkuri(D)	7.6
WID802(D)	7.7
Wollaroi(D)	7.2
Yawa(D)	7.6
Check varieties	
Federation(D) (long)	9.3
Whistler(D) (short)	6.0

Source: Department of Primary Industries New South Wales

Stubble reduces the impact of raindrops on the soil surface and helps prevent soil crusts from forming. Stubble retention also encourages biological activity and increases the amount of organic matter, which improves the stability of the soil by binding the soil particles together. [3]

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. [4]

Salinity

There is increasing evidence for the negative effect of sodium chloride (e.g. saline soils or sea water) on the germination and subsequent growth of durum. In many species, salt sensitivity is associated with the accumulation of sodium (Na+) in photosynthetic tissues. [5] The first study below found that durum seeds were less tolerant to salt at germination than after the three-leaf stage. [6] The second study found that moderate stress intensity (22% seawater osmolarity, –0.62 MPa) only delayed mean germination time, whereas higher seawater osmolarity (37% seawater osmolarity, –1.04 MPa) reduced germination percentage as well. [7]

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

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

5 R Davenport, RA James, A Zakrisson-Plogander, M Tester, R Munns (2005). Control of sodium transport in durum wheat. Plant Physiology, 137(3), 807–818, http://www.plantphysiol.org/content/137/3/807

6 LE Francois, EV Maas, TJ Donovan, VL Youngs (1986). Effect of salinity on grain yield and quality, vegetative growth, and germination of semi-dwarf and durum wheat. Agronomy Journal, 78(6), 1053–1058, https://dl.sciencesocieties.org/publications/aj/pdfs/78/6/AJ0780061053

7 Z Flagella, D Trono, M Pompa, N Di Fonzo, D Pastore (2006). Seawater stress applied at germination affects mitochondrial function in durum wheat (*Triticum durum*) early seedlings. Functional Plant Biology, 33(4), 357–366, http://dx.doi.org/10.1071/FP05244

IN FOCUS

Effect of salinity on grain yield and quality, vegetative growth and germination of semi-dwarf and durum wheat

Semi-dwarf bread wheat (*Triticum aestivum* L.) and durum wheat (*Triticum turgidum* L., durum group) are often grown on saline soils in the western United States. Because of the lack of information on salinity effects on vegetative growth and seed yield of these two species, a two-year field plot study was conducted. Six salinity treatments were imposed on a Holtville silty clay (clayey over loamy, montmorillonitic [calcareous], hyperthermic Typic Torrifluvent) by irrigating with waters salinised with sodium chloride and calcium chloride (1:1 by weight). Electrical conductivities of the irrigation waters were 1.5, 2.5, 5.0, 7.4, 9.9, and 12.4 dS/m the first year, and 1.5, 4.0, 8.0, 12.0, 16.1, and 20.5 deciSiemens per metre (dS/m) the second year. Grain yield, vegetative growth and germination were measured. Relative grain yields of one semi-dwarf wheat cultivar and two durum cultivars were unaffected by soil salinity up to 8.6 and 5.9 dS/m (electrical conductivity of the saturated-soil extract), respectively. Each unit increase in salinity above the thresholds reduced yield of the semi-dwarf cultivar by 3.0% and the two durum cultivars by 3.8%. These results place both species in the salt-tolerant category. Salinity increased the protein content of both grains but only the quality of the durum grain was improved. Vegetative growth of both species was decreased more by soil salinity than was grain yield. Both species were less salt tolerant at germination than they were after the three-leaf stage of growth. [8]

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

The major environmental factors affecting development in wheat are photoperiod and temperature. [9] Genes control the plant's growth responses to the accumulation of temperature, day length 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 day length (photoperiod). [10]

4.2.1 Photoperiod/day length

To ensure the crop flowers at the optimal time, an understanding is required of how sowing time, and subsequent photoperiod range, affects flowering time. Variation in photoperiod response plays an important role in adapting crops to agricultural environments. The longer the days, the shorter the thermal time needed to initiate flowering in photoperiod-sensitive wheat varieties. Photoperiod insensitivity in durum wheat is less characterised. [11]

8 LE Francois, EV Maas, TJ Donovan, VL Youngs (1986). Effect of salinity on grain yield and quality, vegetative growth, and germination of semi-dwarf and durum wheat. Agronomy Journal, 78(6), 1053–1058, https://dl.sciencesocieties.org/publications/aj/pdfs/78/6/AJ0780061053

9 GA Slafer, HM Rawson (1994) Sensitivity of wheat phasic development to major environmental factors: a re-examination of some assumptions made by physiologists and modellers. Australian Journal of Plant Physiology 21(4), 393–426, http://www.publish.csiro.au/paper/PP9940393.htm

10 GRDC (2011) Time of sowing fact sheet. Grains Research and Development Corporation, March 2011, http://www.grdc.com.au/GRDC-FS-TimeOfSowing

11 EP Wilhelm, AS Turner, DA Laurie (2009) Photoperiod insensitive Ppd-A1a mutations in tetraploid wheat (*Triticum durum* Desf.). Theoretical and Applied Genetics, 118(2), 285–294, http://www.ncbi.nlm.nih.gov/pubmed/18839130

In some Australian wheat varieties, photoperiod can also impact the length of time required to reach growth stages. Genetic studies and observations of wheat varieties grown in different latitudes suggest many Australian wheat varieties are day length-sensitive to varying degrees; however, most varieties are not well characterised for responses to day length.

Varieties released before 1973 generally carried a photoperiod-sensitive gene, making them more sensitive to day length. They tended to flower later for a given sowing date when sown before 22 June—on average a week later in the Mallee, compared with current varieties. A photoperiod-sensitive variety will flower four to 12 days later than an insensitive variety when sown early in southern Australia. [12]

4.2.2 Temperature

Heat and/or drought stress during cultivation can affect the processing quality of durum wheat. High temperatures during establishment cause seedling mortality, reducing the number of plants that establish. In hot environments, the maximum temperature in the top 2-3 cm of soil can be 10–15°C higher than the maximum air temperature, especially with a dry, bare soil surface and high radiation intensity. In these conditions, soil temperature can reach 40–45°C, seriously affecting seedling emergence. Brief exposure to extreme soil temperatures can also restrict root growth and tiller initiation. [13]

In the presence of a long period of temperatures in the range of 30–35°C, a dough 'strengthening' effect has been observed, while frequent episodes of daily maximum temperatures above 35°C led to a dough 'weakening' effect, which is not desirable for pasta making. [14]

One study found that plants sown late experienced heat stress in the growth stages after anthesis. Stress tolerance index (STI) and stress susceptibility index (SSI) for grain yield and 1000-grain weight indicated that durum wheat had the lowest STI for grain yield. Barley genotypes had a higher tolerance to post-anthesis heat stress than wheat genotypes. Average grain yield reduction in barley and wheat genotypes exposed to heat stress after anthesis was 17% and 24%, respectively. Higher SSI for 1000-grain weight in late maturity genotypes was related to delay in anthesis and contact of grain growth period with heat stress. [15]

Photoperiod or day length is the number of hours of daylight. Durum wheat is a long-day plant, meaning that it responds to increasing photoperiod. This sensitivity determines whether the plant continues to produce leaves or changes to reproductive development.

Photoperiod can affect the development of wheat by:

causing changes in the rate of leaf area expansion and dry matter production

providing a cue for the start of reproductive development

changing the rate of reproductive development.

Thermal time

Thermal time is a calculation of accumulated temperature. It helps to explain the relationship between plant development and temperature. It is calculated as the mean daily temperature minus a base temperature and is recorded as degree-days (°Cd). The base temperature is the minimum temperature at which the plant grows, and this varies for each crop. For wheat, the base temperature is 0°C during vegetative growth and 3°C in the reproductive phase.

12 GRDC (2011) Time of sowing fact sheet. Grains Research and Development Corporation, March 2011, http://www.grdc.com.au/GRDC-FS-TimeOfSowing

13 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

14 B Borghi, M Corbellini, M Ciaffi, D Lafiandra, E Stefanis, D Sgrulletta, FN Di (1995). Effect of heat shock during grain filling on grain quality of bread and durum wheats. Crop and Pasture Science, 46(7), 1365–1380, http://www.publish.csiro.au/paper/AR9951365.htm

15 A Modhej, R Farhoudi, A Afrous (2015) Effect of post-anthesis heat stress on grain yield of barley, durum and bread wheat genotypes. In Proceedings of the 10th International Barley Genetics Symposium. Alexandria, Egypt, 5–10 Apr 2008, (p. 230), ICARDA

Although not commonly used at farm level, thermal time is very important for predicting the growth stages of some crops. It is not always a good predictor for wheat, as development is also influenced by photoperiod and vernalisation. In general, higher temperatures accelerate development between germination and flowering. However, under increasing photoperiod, thermal time has less effect on plant development.

While the rate of development may be controlled by many factors, higher temperatures and increasing photoperiod reduce the number of days in all growth stages. This is particularly important up until the flowering stage. There is a variation in thermal time between seasons. [16]

IN FOCUS

Heat and drought stress on durum wheat—responses of genotypes, yield and quality parameters

This study examined the effects of drought and heat stress conditions on grain yield and quality parameters of nine durum wheat varieties, grown during two years (2008–09 and 2009–10). More precipitation in 2009–10 may account for the large differences in parameters observed between crop cycles (2008–09 and 2009–10). Combined results of the two crop cycles showed that flour protein content and sodium dodecyl sulfate sedimentation volume increased under both stress conditions, but not significantly. In contrast the gluten strength-related parameters lactic acid retention capacity (LARC) and mixograph peak time increased and decreased significantly under drought and heat stress, respectively. Drought and heat stress drastically reduced grain yield but significantly enhanced flour yellowness. LARC and the swelling index of glutenin could be alternative tests to screen for gluten strength. Genotypes and quality parameters performed differently to drought and heat stress, which justifies screening durum wheat for both yield and quality traits under these two abiotic stress conditions. [17]

4.2.3 Water deficit and water stress

Getting the balance right between too much and too little water is essential in durum growing. Durum wheat production in southern Australia is limited when water deficit occurs immediately before and during anthesis. [18] If durum is water stressed, symptoms of fungal disease will be exacerbated, resulting in the appearance of white heads that produce small shrivelled grain, severely affecting yield. [19]

16 NSW DPI (2008) Wheat growth and development (Eds J White, J Edwards). New South Wales Department of Primary Industries, February 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/516185/Procrop-wheat-growth-and-development.pdf

17 YF Li, Y Wu, N Hernandez-Espinosa, RJ Peña (2013) Heat and drought stress on durum wheat: Responses of genotypes, yield, and quality parameters. Journal of Cereal Science, 57(3), 398–404, http://dx.doi.org/10.1016/j.jcs.2013.01.005

18 H Liu, IR Searle, DE Mather, AJ Able, JA Able (2015) Morphological, physiological and yield responses of durum wheat to pre-anthesis water-deficit stress are genotype-dependent. Crop and Pasture Science, 66(10), 1024–1038, http://www.publish.csiro.au/paper/CP15013.htm

19 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

IN FOCUS

Morphological, physiological and yield responses of durum wheat to pre-anthesis water-deficit stress are genotype-dependent

This study was conducted to determine the effect of genotypic variation on various yield, morphological and physiological responses to pre-anthesis water-deficit stress by evaluating 20 durum wheat genotypes over two years of glasshouse experiments. Grain number was the major yield component that affected yield under pre-anthesis water-deficit stress. Genotypes with less yield reduction also had less reduction in chlorophyll content, relative water content and leaf water potential, suggesting that durum genotypes tolerant of water-deficit stress maintain a higher photosynthetic rate and leaf water status. Weak to moderate positive correlations of morphological traits, including plant height and fertile tiller number, with grain number and biomass make the evaluation of high-yielding genotypes in rain-fed conditions possible. Morphological traits (such as plant height and tiller number) and physiological traits (such as chlorophyll content, relative water content and leaf water potential) could therefore be considered potential indicators for indirect selection of durum wheat with water-deficit stress tolerance under Mediterranean conditions. [20]

IN FOCUS

Effect of water stress at various growth stages on some quality characteristics of winter wheat

A field experiment has been carried out on winter wheat to analyse the effect of water stress (fully irrigated [FI], rain-fed [R], early water stress [EWS], late water stress [LWS] and continuous water stress [CWS]) at different growth stages on quality characteristics. Water stress had a substantial effect on most of the quality characteristics recorded. CWS, EWS, R and LWS treatments decreased grain yields by 65.5, 40.6, 30.5 and 24.0%, respectively, compared with the FI treatment. CWS increased grain protein content by 18.1%, sedimentation volume by 16.5%, wet gluten content by 21.9% and decreased 1000-kernel weight by 7.5 g compared with FI treatment. LWS caused an increase of 8.3% in grain protein content, 8.7% in sedimentation volume, 10.8% in wet gluten content and a reduction of 3.8 g in 1000-kernel weight compared with FI. EWS and R increased sedimentation volume and wet gluten content, but decreased 1000-kernel weight compared with FI. The effect of LWS on grain quality was more significant than that of EWS. The results suggest that soil moisture conditions increase grain yield and kernel weight of winter wheat but decrease its quality. [21]

20 H Liu, IR Searle, DE Mather, AJ Able, JA Able (2015) Morphological, physiological and yield responses of durum wheat to pre-anthesis water-deficit stress are genotype-dependent. Crop and Pasture Science, 66(10), 1024–1038, http://www.publish.csiro.au/paper/CP15013.htm

21 A Ozturk, F Aydin (2004) Effect of water stress at various growth stages on some quality characteristics of winter wheat. Journal of Agronomy and Crop Science, 190(2), 93–99, http://dx.doi.org/10.1071/FP05244

4.2.4 Salinity

A saline soil is one that contains sufficient soluble salts (most commonly sodium chloride) to adversely affect the growth of plants. Salinity reduces a plant's ability to extract water from the soil and can cause toxicities from specific ions. The susceptibility of various crops, including durum wheat, to yield decline under saline conditions is shown in Table 2.

Table 2: *Susceptibility of various crops to yield decline with saline soil and irrigation water.*

	Electrical conductivity (EC) causing 5% yield reduction (D S/m)			
		EC of water sample (i.e. irrigation salinity)		
Crop	**EC of a soil extract (root zone salinity)**	**Well drained soils**	**Moderate to slow draining soils**	**Very slow draining soils**
Barley-forage	6.0	6.0	4.0	2.0
Barley-grain	8.0	8.0	5.3	2.6
Canola	6.5	6.5	4.3	2.1
Faba Beans	1.8	1.8	1.2	0.6
Oats	5.0	5.0	3.3	1.7
Wheat	6.0	6.0	4.0	2.0
Durum wheat	5.7	5.7	3.8	1.9
Cotton	2.4	Not recorded	1.6	1.8
Maize	1.7	1.7	1.1	0.6
Soybeans	0.8	0.8	0.5	0.3
Sunflowers	5.5	5.5	3.6	Not recorded
Millet	6.0	6.0	4.0	2.0
Sorghum grain	1.5	1.5	1.0	0.5
Rice	3.0	Not recorded	Not recorded	1.0

Source: Soil Quality Pty Ltd

IN FOCUS

Factors affecting CO_2 assimilation, leaf injury and growth in salt-stressed durum wheat

To examine the factors that affect tolerance to high internal salt concentrations, two tetraploid wheat genotypes that differ in the degree of salt-induced leaf injury (Wollaroi(D and Line 455) were grown in 150 mM sodium chloride for four weeks. Shoot biomass of both genotypes was substantially reduced by salinity, but genotypic differences appeared only after three weeks, when durum cultivar Wollaroi(D showed greater leaf injury and a greater reduction in biomass than Line 455. Salinity caused a large decrease in stomatal conductance of both genotypes. High Na+ and Cl- concentrations in the leaf and chlorophyll degradation, indicates that these later reductions in CO_2 assimilation in Wollaroi(D were a consequence of a direct toxic ion effect. The earlier reduction in CO_2 assimilation and greater leaf injury explain why growth of Wollaroi(D was less than Line 455. [22]

MORE INFORMATION

Salinity training manual

4.2.5 Effects of nitrogen

Nitrogen (N) is essential to plant growth, with high N levels required to ensure durum reaches its ideal protein potential of 13%. [23] Nitrogen is an essential nutrient required for growth, and impacts on root development which in turn affects shoot growth, access to water and other essential nutrients. In south-eastern Australia, many soils are naturally deficient in N. [24]

N is highly mobile in wheat hence when N is deficient, older leaves yellow as N is mobilised to younger plant parts including grain. Other symptoms of N deficiency are stunting of the plant, a reduction in the number of tillers, grain with a mottled colouring and lower grain yield. [25]

Soil N supply is particularly important in rotations that include legume crops and pastures. Durum is often grown following legumes to benefit from increased available N in the soil. N in the residues of legume crops and pastures is decomposed by microorganisms and will become available to subsequent crops. For example, 20–25% of the N fixed by a medic pasture was converted to mineral forms of N and taken up by the following crop. [26]

N is commonly applied in moderate to high levels during seedbed preparation, with anhydrous ammonia or urea often used. N can be leached from light soil if heavy rain or continuous wet weather delays sowing. Excessive N fertiliser applied close to the seed can also lead to toxicity problems.

For more information on the use of nitrogen in durum growing, see Section 5: Nutrition and fertiliser.

22 RA James, AR Rivelli, R Munns, S von Caemmerer (2002) Factors affecting CO_2 assimilation, leaf injury and growth in salt-stressed durum wheat. Functional Plant Biology, 29(12), 1393–1403, http://www.publish.csiro.au/paper/FP02069.htm

23 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

24 CropPro, Nitrogen as a nutrient for wheat in southern Australia, http://www.croppro.com.au/resources/Review%20-%20Nitrogen%20for%20Wheat.pdf

25 NJ Grundon (1987) Hungry crops: a guide to mineral deficiencies in field crops. Queensland Department of Primary Industries, pp 19, ISBN 0724223150

26 JF Angus, MB Peoples (2012) Nitrogen from Australian dryland pastures. Crop and Pasture Science, 63(9), 746–758, http://dx.doi.org/10.1071/CP12161

4.2.6 Effects of phosphorus

Phosphorus (P) is essential for 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 six weeks. P is relatively immobile in the soil (unlike N), so needs to be placed near the seed and cannot be top-dressed. Regardless of soil test results, some P should be applied at sowing in close proximity to the seed.

4.3 Plant growth stages

Plants grow as green leaves intercept energy from the sun and use that energy to capture carbon (from atmospheric carbon dioxide) and manufacture carbohydrates that are used to grow the leaves and other structures of the plant. Over the life cycle of the plant the allocation of carbon changes as the plant moves through a series of developmental stages. In cereals the key developmental stages are associated with changes in the shoot apex as the head is formed and the stems elongate. The latter is a critical developmental phase as potential yield (number of grains and grain size) is determined at this time. Flowering (anthesis) in cereals is another critical developmental stage and post-anthesis growth is allocated almost entirely to grain filling. [27]

Growth in cereals can be thought of in two distinct parts:

1. Pre-flowering (pre-anthesis) growth, which is the growth that goes into leaves, roots and stems before a crop flowers and sets yield potential.
2. Post-flowering growth, the majority of which goes into grain. [28]

Durum crops grow to about 80 cm at maturity (15–20 cm shorter than bread wheat) depending on seasonal conditions and variety. Low density crops tend to have heads flowering over a longer interval. Such a prolonged flowering period may reduce the impact of a frost around flowering. Protracted moist weather at flowering can have an adverse effect on pollination by inhibiting the release of pollen from the anthers. If the female part of the flower (the stigma and ovule) is not fertilised while in its receptive phase, a grain will not develop. Low density crops are likely to use available soil moisture reserves at a slower rate than the higher density crops. Avoidance of moisture stress before and at flowering is critical for satisfactory grain set, as pollen will abort during periods of stress as part of a natural survival mechanism of the plant. Extended flowering could reduce the risk of pollination failure caused by frost or extended moist weather. The time difference in reaching full maturity between early-flowering and late-flowering tillers is usually small; therefore, the early heads are not likely to be ripe for many days ahead of the later heads (Photo 2). Harvesting should not be delayed significantly. [29]

27 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

28 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

29 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

Photo 2: *Early durum heads are not likely to ripen well ahead of later heads.The Zadoks cereal growth stage key provides farmers, advisers and researchers with a common reference for describing the crop's development and allow implementing of agronomic decisions based on a common understanding of which stage the crop has reached. Management by growth stage is critical to optimise returns from inputs such as N, plant growth regulators, fungicides and water.*

Source: Clove Garden

4.3.1 Zadoks Cereal Growth Stage Key

The Zadoks growth stage key provides a common reference to describe the crop's development and the stages at which to apply key inputs. This is the most commonly used key to growth stages for cereals, in which 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.

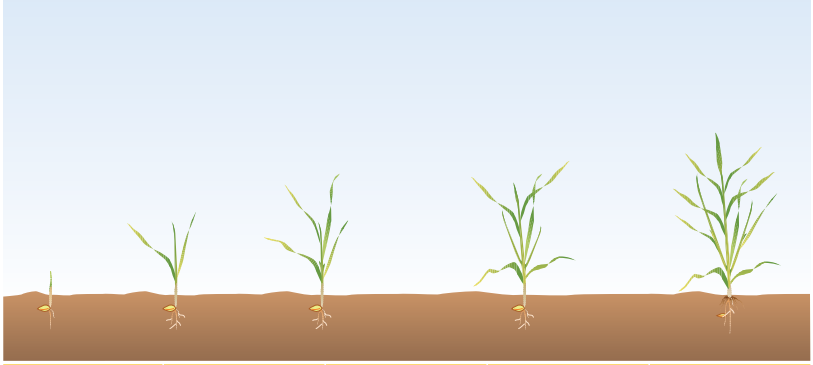
Key growth stages in relation to disease control and canopy management

The principal Zadoks growth stages (Figure 1) used in relation to disease control and N management are those from the start of stem elongation through to early flowering: GS30–GS61. [30]

Early stem elongation GS30–GS33 (pseudo stem erect—third node on the main stem)

This period is important for N timing, growth regulants 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.

30 GRDC (2005) Cereal growth stages. Grains Research and Development Corporation, September 2005, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf



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

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

Figure 1: *Zadoks growth stages.* .

Key points: Zadoks growth stage key

- The Zadoks 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 (due to leaf senescence) during tillering. The plant growth stage is determined by main stem and number of tillers per plant, for example GS22 is main stem plus two tillers up to GS29 main stem plus nine or more tillers.
- In Australian cereal crops plants rarely reach GS29 before the main stem starts to stem elongate (GS30).
- As a consequence 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, GS23 and GS17, yet practically would be regarded as GS32, since this describes the most advanced stage of development.
- After stem elongation (GS30) the growth stage describes the stage of the main stem, it is not an average of all the tillers. This is particularly important with

fungicide timing, for example GS39 is full-flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged.

- Use a ruler to measure node movement in the main stem to define early stem elongation growth stages.
- Take care not to confuse the basal node at the stem base with the first true node. Basal nodes are usually signified by a constriction of the stem below the node with an incompletely formed internode space, it is the point where the lowest leaves attach to the stem. Further, basal nodes will often grow small root tips. This is not the first node.
- Nodal growth stage can give an approximate guide to which leaf is emerging from the main stem, this can save time with leaf dissection when it comes to making decisions on fungicide application pre-flag leaf (when all leaves are emerged).
- The rate of development influences the time between growth stages—later sowings spend less time in each development phase including grainfill.
- Though it will vary between varieties and regions (due to temperature), stem elongation leaves emerge approximately five to 10 days apart (10 under cooler temperatures at the start of stem elongation and nearer five to seven days as the flag comes out.)
- The period of time between leaf emergences is referred to as the phyllochron and is approximately 100–120 degree-days, though it can be longer or shorter depending on variety. [31]

4.3.2 Why is growth stage important in making fungicide, nitrogen application and growth regulant decisions?

The start of stem elongation is particularly important for decisions on fungicide and nitrogen inputs, as it marks the emergence of the first of the important yield-contributing leaves and the point at which N uptake in the plant strongly increases. [32]

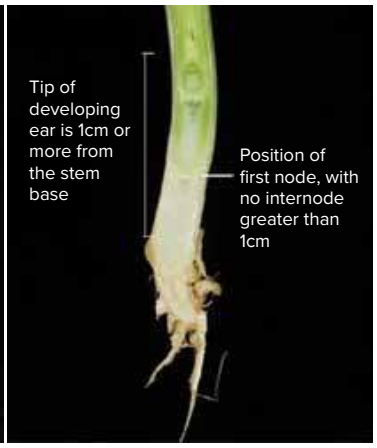
To correctly identify these growth stages, main stems of the cereal plants are cut longitudinally and the position of nodes (joints in the stem) and the length of internodes (cavity in the stem between nodes) are measured with a ruler (Figure 2).

31 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

32 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

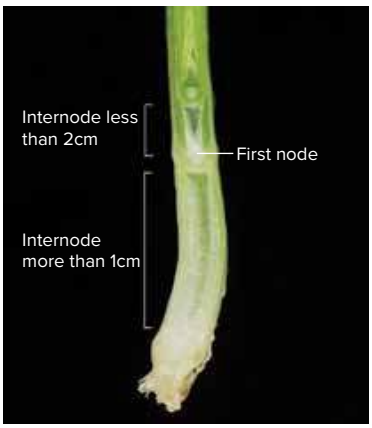
GS30 The tip of the developing ear is one centimetre of more from the base of the stem where the lowest leaves attach to the shoot apex.

Preparation of main stem for measurement

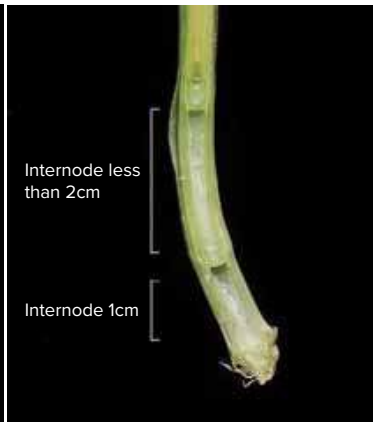


GS30 - Main stem with embryo ear at 1cm.

GS31 The first node can be seen 1cm or more above the base of the shoot (with clear internode space below it) and the internode above it is less than 2cm



GS31 - Early first node formation



GS31 - second node as less than 2cm from first node

Figure 2: *Dimensions defining stem elongation with internal stem base dimensions.*

Source: Grains Research and Development Corporation

Nutrition and fertiliser

Key messages:

- Soils require adequate nutritional properties to support yield targets.
- Previous plants and crops remove nutrients from the soil, which will need to be replaced by strategic rotations or chemical supplements.
- Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils.
- It is important to test soil for nitrogen to the effective rooting depth of the crop.
- Correct nitrogen application timing is essential. Too much nitrogen applied early can result in durum setting an unattainable yield potential with resultant high grain screenings levels. [1]
- Depending on location, other nutrients may need to be applied, such as phosphorus, sulfur and, on highly alkaline soils, zinc and manganese.

5.1 Soil nutrition

In south-eastern Australia profitable grain production depends on applied fertilisers, particularly nitrogen (N), phosphorus (P) and to a lesser extent, potassium (K), sulfur (S), zinc (Zn), manganese (Mn) and copper (Cu). [2] The natural fertility of cropped agricultural soils is declining over time. Grain growers must continually review their management programs to ensure the long term sustainability of high quality grain production.

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. [3]

In the acid soils of southern Victoria poor wheat growth is often related to soil sodicity, excess acidity/high aluminium or Mn toxicity, or the physical constraints of waterlogging and high bulk density. [4] In the neutral and alkaline soils of north-west Victoria and the cropping areas of South Australia (SA), wheat production is principally constrained by excess alkalinity, salinity, sodicity or boron in subsoils.

There is a hierarchy of crop fertility needs: there must be sufficient plant-available N to get a response to P and there must be sufficient P for S and/or K responses to occur. Additive effects of N and P appear to account for most of the above-ground growth and yield response. [5]

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

1 GRDC (2014) Durum quality and agronomy fact sheet. Grains Research and Development Corporation, March 2014, https://grdc.com.au/GRDC-FS-Durum

2 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

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

4 Conyers et al. 2003, MacEwan et al. 2010 in http://www.croppro.com.au/resources/Review%20-%20Soil%20constraints%20for%20wheat.doc

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

of clay and organic matter particles in the root-zone, and be supplied when and where the plant needs it. Temperature and soil moisture affect the availability of nutrients to plants, and the availability of nutrients also depends on soil pH, degree of exploration of root systems and various soil chemical reactions, which vary from soil to soil. Fertiliser may be applied in the top 5–10 cm, but unless the soil remains moist, the plant will not be able to access it. Movement of nutrients within the soil profile in low-rainfall areas is generally low, except in very sandy soils, and some nutrients such as P and Zn are relatively immobile in the soil. Lack of movement of nutrients, combined with current farming methods (e.g. no-till), is resulting in stratification of these nutrients, with concentrations building up in the surface of the soil where they are not always available to plants. [6]

With more frequent use of opportunity cropping, improved farming techniques and higher yielding varieties, nutrition programs should be reviewed regularly. 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. [7]

MORE INFORMATION

Ground Cover Issue 97: More profit from nutrition

VIDEOS

WATCH : Over the Fence: Precision agriculture pays at Mildura

5.2 Crop removal rates

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. In durum, N is an essential nutrient to reach 13% protein. As a rule of thumb, for every tonne per hectare of high protein grain harvested, about 50 kg of N is removed in the grain. This amount of N must be replaced, together with other N losses such as from leaching and de-nitrification. [8]

Table 1: *Average nutrients removed by wheat crops (all figures are kg/ha).*

	Yield	N	P	K	Ca (calcium)	Mg (magnesium)	S	Zn
Irrigated wheat	7,000	125	24	35	3.5	10	3	200
Dryland wheat	2,000	40	7	10	1.5	2.8	5.5	60

Source: DAFF

5.3 Soil testing

Fertiliser is a major cost for grain growers, so making careful selections of crop nutrients is a major determinant of profit. Both under-fertilisation and over-fertilisation can lead to economic losses due to unrealised crop potential or wasted inputs. Before deciding on how much fertiliser to apply, it is important to understand the quantities of available nutrients in the soil, where they are located in the soil profile and the likely demand for nutrients in that season. Soil sampling to the full depth of root exploration prior to sowing should be a good guide to the available soil N supply. The values from appropriate soil tests can be compared against critical nutrient values and ranges; these indicate which nutrients are limiting or adequate. Soil test critical values advise growers if a crop is likely to respond to added fertiliser, but without further information they do not predict optimum fertiliser rates. When

6 DAFQ (2012) Wheat production: nutrition. Department of Agriculture and Fisheries Queensland, September 2012, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition

7 M Blumenthal, I Fillery (2012) More profit from crop nutrition. GRDC Ground Cover Supplement Issue 97. Grains Research and Development Corporation, March–April 2012, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-issue-97-MarApr-2012-Supplement-More-profit-from-nutrition/More-profit-from-crop-nutrition

8 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

considered in combination with information about target yield, available soil moisture, last year's nutrient removal and soil type, soil tests can help in making fertiliser decisions. [9]

Principal reasons for soil testing for nutrition:

- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity) and salinity, which affect crop demand as well as its ability to access nutrients;
- zoning paddocks for variable application rates; and
- as a diagnostic tool to identify reasons for poor plant performance. [10]

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; and
- 2 M KCl extractable inorganic N, which provides measurement of nitrate-N and ammonium-N. [11]

Sampling depth

Soil sampling to greater depth (0 to 60cm) is considered important for more mobile nutrients (N, K and S) as well as for pH, salinity and sodicity and boron which is often at toxic levels deeper in the soil profile in many low to medium rainfall cropping areas of southern Australia.

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 sub-sample is taken to the full sampling depth.
- Do not sample in very wet conditions.
- Shortcuts in sampling—such as taking only one or two cores, a handful or a spadeful of soil—will give misleading results. As a rule, 20 to 30 cores from a uniform soil zone in a paddock should be combined to make a single sample for testing.
- Avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers or other sources of nutrients such as sunscreen, which can contain zinc. [12]

MORE INFORMATION

Soil testing for crop nutrition – southern region factsheet.

5.4 Plant and/or tissue testing for nutrition levels

Plant tissue testing can also be used to diagnose a deficiency or monitor the general health of the pulse crop. Plant tissue testing is most useful for monitoring crop health, because by the time noticeable symptoms appear in a crop the yield potential can be markedly reduced.

9 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

10 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

11 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

12 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

5.4.1 Why measure nutrients in plant tissues?

Of the many factors affecting crop quality and yield, soil fertility is one of the most important. It is fortunate that producers can manage fertility by measuring the plant's nutritional status. Nutrient status is an unseen factor in plant growth, except when imbalances become so severe that visual symptoms appear on the plant. The only way to know whether a crop is adequately nourished is to have the plant tissue analysed during the growing season.

5.4.2 What plant tissue analysis shows

Plant tissue analysis shows the nutrient status of plants at the time of sampling. This, in turn, shows whether soil nutrient supplies are adequate. In addition, plant tissue analysis will detect unseen deficiencies and may confirm visual symptoms of deficiencies. Toxic levels also may be detected. Though usually used as a diagnostic tool for future correction of nutrient problems, plant tissue analysis from young plants will allow a corrective fertiliser application that same season. A plant tissue analysis can pinpoint the cause, if it is nutritional.

A plant analysis is of little value if the plants come from fields that are infested with weeds, insects, and disease organisms; if the plants are stressed for moisture; or if plants have some mechanical injury.

The most important use of plant analysis is as a monitoring tool for determining the adequacy of current fertiliser practices. Sampling a crop periodically during the season or once each year provides a record of its nutrient content that can be used through the growing season or from year to year. With soil test information and a plant analysis report, a producer can closely tailor fertiliser practices to specific soil-plant needs.

Do

- Sample the correct plant part at the specified time or growth stage for the particular nutrient in question.
- Different plant tissue samples are used for diagnoses of different nutrients..
- Use clean plastic disposable gloves to sample to avoid contamination.
- Sample tissue (e.g. entire leaves) from vigorously growing plants unless otherwise specified in the sampling strategy.
- Take sufficiently large sample quantity (adhere to guidelines for each species provided).
- When trouble shooting, take separate samples from good and poor growth areas.
- Wash samples while fresh where necessary to remove dust and foliar sprays.
- Keep samples cool, after collection.
- Refrigerate or dry if samples can't be dispatched to the laboratory immediately, to arrive before the weekend.
- Generally sample in the morning while plants are actively transpiring.

Don't

- Avoid spoiled, damaged, dead or dying plant tissue.
- Don't sample plants stressed by environmental conditions.
- Don't sample plants affected by disease, insects or other organisms.
- Don't sample soon after applying fertiliser to the soil or foliage.
- Avoid sample contamination from dust, fertilisers, chemical sprays as well as perspiration and sunscreen from hands.
- Avoid atypical areas of the paddock, e.g. poorly drained areas.
- Do not sample plants of different vigour, size and age.
- Do not sample from different cultivars (varieties) to make one sample.

- Don't collect samples into plastic bags, as this will cause the sample to sweat and hasten its decomposition.
- Don't sample in the heat of the day, i.e. when plants are moisture stressed.
- Don't mix leaves of different ages. [13]

Once you start taking samples, it's critical to get the right plant part at the right growth stage (Table 2). A general rule of thumb is to use the most recently matured, fully developed leaf for more mature plants. For young plants, you can generally use the entire plant. For high-value crops, the petiole is used. [14]

Table 2: *Guidelines for sampling plant tissue in wheat.*

Growth stage to sample	Plant part	Number of samples required
Seedling to early tillering (GS 14–21)	Whole tops cut off 1 cm above ground	40
Early tillering to first node (GS 23–31)	Whole tops cut off 1 cm above ground	25
Flag leaf ligule just visible to boots swollen (GS 39–45)	Whole tops cut off 1 cm above ground	25
Early tillering to first node (GS21–31)	Youngest expanded blade plus next two lower blades	40

Source: Back Paddock Company

5.5 Nitrogen

Key points:

- N is needed for crop growth in larger quantities than any other nutrient.
- Nitrate (NO3-) is the highly mobile form of inorganic N in both the soil and the plant.
- Sandy soils in high rainfall areas are most susceptible to nitrate loss through leaching.
- Soil testing and N models will help determine seasonal N requirements.

Nitrogen (N) is an essential nutrient for plant growth, development and reproduction. Despite N being one of the most abundant elements on earth, N deficiency is probably the most common nutritional problem affecting plants worldwide, as N from the atmosphere and earth's crust is not directly available to plants. N is so vital because it is a major component of chlorophyll, the compound through which plants use sunlight energy to produce sugars from water and carbon dioxide (i.e. photosynthesis). It is also a major component of amino acids, the building blocks of proteins. Without proteins, plants wither and die. Soil N exists in three general forms: organic N compounds, ammonium (NH4+) ions and nitrate (NO3-) ions. At any given time, 95–99% of the potentially available N in the soil is in organic forms: in plant and animal residues, in the relatively stable soil organic matter or in living soil organisms (mainly microbes such as bacteria). This N is not directly available to plants, but some can be converted to available forms by microorganisms. [15] In south-eastern Australia, many soils, especially light soils, are naturally deficient in N. [16] The N cycle in Figure 1 illustrates how N is converted between the many different forms.

13 Back Paddock SoilMate. Guidelines for sampling plant tissue for annual cereal, oilseed and grain legume crops, http://www.backpaddock.com.au/assets/Product-Information/Back-Paddock-Sampling-Plant-Tissue-Broadacre-V2.pdf?phpMyAdmin=c59206580c88b2776783fdb796fb36f3

14 The Fertiliser Institute (2016) Plant tissue analysis tells the story. http://www.nutrientstewardship.com/implementation/article/plant-tissue-analysis-tells-story#sthash.kUljaDGs.dpuf

15 The Mosaic Company (2016) Nitrogen in plants. Mosaic Crop Nutrition, http://www.cropnutrition.com/efu-nitrogen

16 CropPro. Nitrogen as a nutrient for wheat in southern Australia. http://www.croppro.com.au/resources/Review%20-%20Nitrogen%20for%20Wheat.pdf

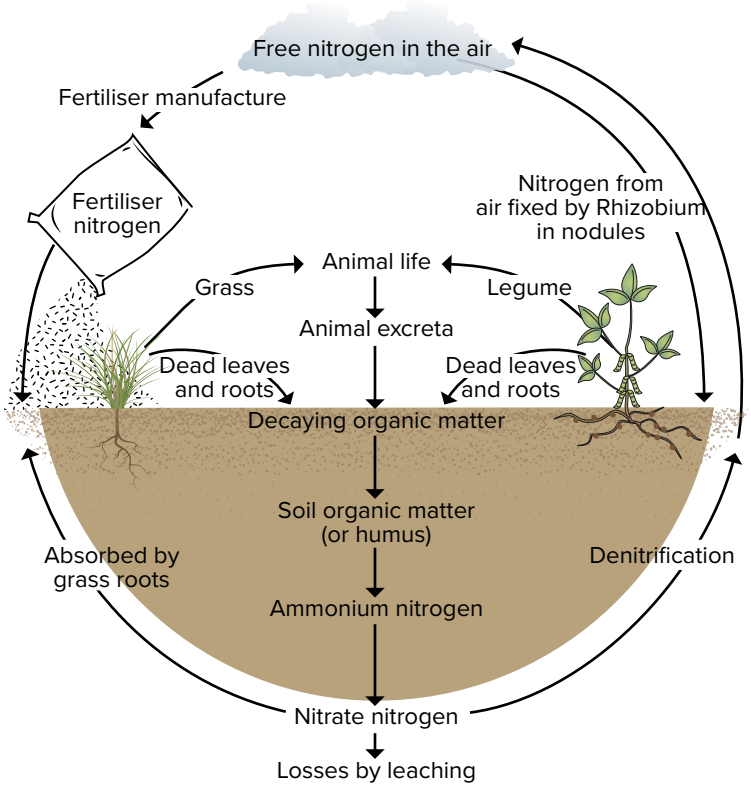


Figure 1: *The nitrogen cycle in soil, plants and the atmosphere.*

MORE INFORMATION

Nitrogen as a nutrient for wheat in southern Australia

Nitrogen management

FAQ

5.5.1 Nitrogen and durum

Crop nutrition is critical to the durum crop to achieve a high quality product. Nitrogen availability is an important constraint for durum production, because protein >12% in semolina is desired by pasta manufacturers. Nitrogen allows more photosynthesis by increasing the leaf area index and number of grains per spikelet, thus increasing grain yield. Nitrogen is essential for both optimum yield and grain protein content, and N applications are therefore required where N is deficient in the soil or with irrigation when high grain yield and protein are desired, as N requirements increase with increasing moisture availability. [17]

To obtain high protein levels soil N management requires careful planning. Paddocks with deep soil and high residual N fertility are suitable for growing dryland durum wheat. For the production of a 3 t/ha crop with 13% protein, access to 140 kg N/ha is necessary. [18]

5.5.2 Symptoms of nitrogen deficiency

Paddock:

- Light green to yellow plants particularly on sandy soils or unburnt header or windrows (Photo 1).
- Double sown areas have less symptoms if N fertiliser was applied at seeding. [19]

17 M Sissons, B Ovenden, D Adorada, A Milgate (2014). Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

18 DAFQ (2012) Durum wheat in Queensland. Queensland Department of Agriculture and Fisheries, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

19 DAFWA (2015) Diagnosing nitrogen deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1995

Photo 1: *N deficiency on unburnt header row.*

Source: DAFWA

Plant:

- Plants are pale green with reduced bulk and fewer tillers.
- Symptoms first occur on oldest leaf, which becomes paler than the others with marked yellowing starting at the tip and gradually merging into light green.
- Other leaves start to yellow and oldest leaves change from yellow to almost white (Photo 2).
- Leaves may not die for some time.
- Stems may be pale pink.
- Nitrogen deficient plants develop more slowly than healthy plants, but maturity is not greatly delayed.
- Reduced grain yield and protein levels. [20]

20 DAFWA (2015) Diagnosing nitrogen deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1995

VIDEOS

WATCH : GCTV14: N deficiency

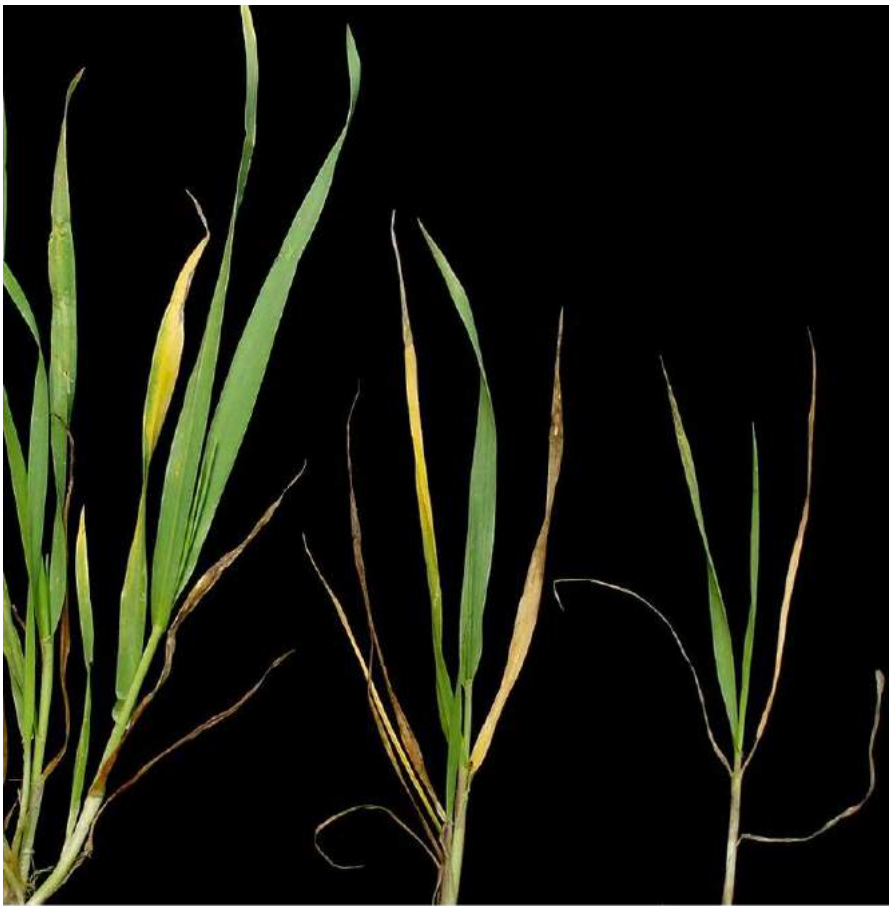


Photo 2: *Nitrogen deficient plants are smaller with yellow leaves and fewer tillers.*

Source: Department of Agriculture and Food Western Australia

5.5.3 Predicting nitrogen supply

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 wheat yield response to applied N. This is usually due to the effect of stored water and in-season rainfall. For non-legume crops, crop N requirement and the ability of the soil to supply N depends on a range of variables, including inorganic and organic N content of the soil, in-crop mineralisation, rate of nitrate leaching, rotation history and presence of yield limitations (such as root disease) and abiotic constraints (such as salinity and sodicity). 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 identify how much N is being mineralised. Surrogate measurements of crop N using canopy sensors are a better alternative. Nitrogen fertiliser recommendations 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 aim to predict the soil processes of mineralisation, immobilisation, leaching, volatilisation, denitrification and plant uptake. They are built into models such as Yield Prophet and Select Your Nitrogen. Yield Prophet requires a detailed characterisation of the physical and chemical properties of the soil profile explored by roots. [21]

21 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

5.5.4 Managing nitrogen levels

Key points:

- In environments where yields are consistently greater than 2.5 t/ha, N applications can be delayed until stem elongation without any loss in yield. In lower yielding environments, the chance of achieving a yield response similar to that achieved with an application at sowing is less.
- There is no consistent difference in the response to N between different forms of N fertiliser.
- In general, increases in grain protein concentration are greater with N applications between flag leaf emergence and flowering.
- Volatilisation losses can be significant in some cases and the greatest risk is with urea and lower with UAN and ammonium sulphate. [22]
- N-rich strips are a useful tool for showing crop N status and fertiliser needs. With mineralisation stable across and either side of the strip, it can indicate potential N response.

Rotations

Ideally durum should be planted into a rotation following a grain or pasture legume phase. Legumes and pasture species (e.g. field peas, faba beans, lupins, lentils, clover, *Medicago* spp.) convert atmospheric N to organic N through symbiotic relationship with bacterium. [23] Alternatively, use cropping history (Table 3) in conjunction with soil tests to calculate an N budget. It is important to test soil for N to the effective rooting depth of the crop. Nitrogen fertiliser is now an expensive input in farming systems, and so it is important for crop profitability that application rates are appropriate. Depending on the location, requirements for other nutrients may need to be managed, including P, S and, on highly alkaline soils, Zn. [24]

Table 3: *Effects of different rotations on soil total N (t/Ha) to 30 cm and as gain relative to continuous wheat.* [25]

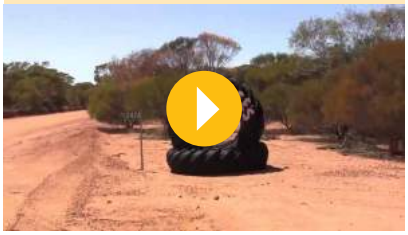
		Soil total N	
Rotation	Wheat crops	0–30 cm	Gain
Grass/legume ley 4 years	0	2.91	0.55
Lucerne ley (1–2 years)	2–3	2.56	0.20
Annual medic ley (1–2 years)	2–3	2.49	0.13
Chickpeas (2 years)	2	2.35	0.00
Continuous wheat (4 years)	4	2.36	–

Fertiliser

Fertiliser rates should be aimed at producing a finished protein level at ADR1 (≥13%). The N harvested in the grain must be replaced, together with other N losses such as from leaching and de-nitrification. The amount of N fertiliser required can be calculated when the percentage of elemental N is known for the fertiliser product (e.g. urea N 46%, anhydrous NH3 82%). [26]

VIDEOS

Watch: Over the Fence West: Building soil nitrogen without the input costs



22 G McDonald, P Hooper P (2013) Nitrogen decision—Guidelines and rules of thumb, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/N-decision-Guidelines-and-rules-of-thumb

23 CropPro Nitrogen as a nutrient for wheat in southern Australia. http://www.croppro.com.au/resources/Review%20-%20Nitrogen%20for%20Wheat.pdf

24 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

25 Hossain SA, Dalal RC, Waring SA, Strong WM and Weston EJ (1996) Comparison of legume-based cropping systems at Warra, Queensland. I. Soil nitrogen accretion and status, Australian Journal of Soil Research 34: 273–287.

26 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

The use of split N applications can be used to achieve increases in biomass (grain yield), and if N is applied after the vegetative stages near to anthesis, this usually results in increases in grain protein content, grain protein yield, grain weight and HVK. [27] Large amounts of early applied N should be avoided in varieties with inherent small grain because it increases the risk of downgrading from small grain screenings. The new durum varieties require more N to achieve 13% protein, but this should only be applied as late as possible to minimise the potential for increased screenings. On sites both responsive and non-responsive to applied N, durum varieties have responded similarly in yield and in many quality measurements with applied N, but they have shown large differences in grain screenings. The new varieties are also able to yield higher than the older varieties with the same amount of N supply, often resulting in lower grain protein. [28]

IN FOCUS

GRDC Final Report – Durum expansion in SA through improved agronomy – when to apply nitrogen

Across all N trials in SA's South East, Mid North and Yorke Peninsula regions, Hyperno(D and Yawa(D have been downgraded the most frequently for low grain protein. As a result, growers may need to apply more N to achieve ADR1 grade. In 2011, an additional 40 kg/N (additional to 80 kg/N previously applied in other varieties) was applied at flag leaf emergence, resulting in 13% protein and ADR1 in higher yielding lines Hyperno(D and Yawa(D at Bordertown and Paskeville. The trials have shown that while the amount of N is important, the timing of the N application is equally as important, particularly with respect to grain size. One of the challenges in achieving 13% grain protein in a variety such as Yawa(D is managing the increased sensitivity in screening levels that occur with applied N, and when grain protein increases. Large amounts of N applied early, before growth stage (GS) 31, have predisposed Yawa(D—with its inherently small grain—to quality downgrading because of high screenings, whereas varieties with inherently larger grain (Tjilkuri(D and Caparoi(D) were not downgraded across early N treatments and appear to be less sensitive to an oversupply of early N. Across all trials, the most effective method to apply more N and reduce the likelihood of quality downgrading (by maintaining grain size) was to adopt a strategic approach to applying N (e.g. later in the growing season or with split applications). An example of this was at Hart in 2011, where applying N later than the onset of stem elongation meant the extra N was translocated to grain protein. Applying N earlier resulted in increased vegetative growth. Too much early vegetative growth results in more water use, and can potentially set an unattainable yield potential (more grains/m^2). Both factors predispose crops to smaller grain if spring conditions are less favourable. Growers are concerned that if N is applied late they may be missing out on achieving maximum yields, but across all trials the maximum yields in durum appear to be achieved in the range of a minimum 10.5–11% protein. Growers, therefore, only need to apply enough N before stem elongation to achieve a 10.5-11% protein in their target yield potential; additional N (e.g. oversupply) during this period may only predispose some varieties to quality downgrading from small grain screenings. The extra N needed for grain protein can be applied later from flag leaf emergence and reassessed based on seasonal conditions. [29]

27 M Sissons, B Ovenden, D Adorada, A Milgate (2014). Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

28 GRDC (2012) Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DGA00001

29 GRDC (2012) Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DGA00001

Timing of application

Grain yield improvements are mainly caused by increased tiller numbers and grains per ear, both of which are determined early in the life of a wheat plant. A sufficient supply of N during crop emergence and establishment is critical. N use efficiency can be improved by delaying fertiliser application until the crop's roots system is adequately developed. This can be three to four weeks after germination.

Later N applications can also have yield benefits through increased tiller survival, leaf duration and photosynthetic area. Delaying application however, reduces the chance that economic response to N will be achieved. An advantage of late applications at GS 31 (1st node visible) is that growers have a better idea of yield potential and pending favorable seasonal conditions before applying the N. [30]

Budgeting

The critical factor in budgeting is the target yield, and protein as crop yield potential is the major driver of N requirement. As a guide, Table 4 shows the N required for different yield and protein combinations at maturity and anthesis. For example, if you are targeting a 3 t/ha crop at 11% protein you would need to have about 62 kg N/ha taken up by the crop by flowering. The amount of fertiliser N required will depend on your estimate of fertiliser recovery, but if you work on a 50% recovery, you would need to supply 124 kg N/ha.

Clearly, predicting yield during the growing season is crucial to allow growers to make tactical decisions on N management. Recent experience in the mid-North of South Australia has shown that Yield Prophet® can predict yields accurately in mid-August and can assist with N decisions. Other tools, such as the PIRSA-CSIRO N calculator, provide a way of calculating N budgets and estimating N requirements. [31]

Table 4: *N requirements for cereal crops at different combinations of yield and grain protein at maturity and the corresponding N required at anthesis. The estimates are based on the assumption that 75% of the total crop N is in the grain at maturity and that 80% of the total N is taken up by anthesis.*

Grain Yield (t/ha)	Growth Stage	Grain Protein(%) 9	10	11	12	13
		(kgN/ha)				
1	Maturity	21	23	26	28	30
	Anthesis	17	19	21	22	24
2	Maturity	42	47	51	56	61
	Anthesis	34	37	41	45	49
3	Maturity	63	70	77	84	91
	Anthesis	51	56	62	67	73
4	Maturity	84	94	103	112	122
	Anthesis	67	75	82	90	97
5	Maturity	105	117	129	140	152
	Anthesis	84	94	103	112	122
6	Maturity	126	140	154	168	182
	Anthesis	101	112	124	135	146

Source: GRDC

30 R Quinlan, A Wherrett (2013) Nitrogen—NSW, http://www.soilquality.org.au/factsheets/N-nsw

31 G McDonald, P Hooper P (2013) Nitrogen decision—Guidelines and rules of thumb, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/N-decision-Guidelines-and-rules-of-thumb

5.6 Phosphorus

Key Points

- Phosphorus (P) is one of the most critical and limiting nutrients in agriculture in Australia.
- P cycling in soils is complex.
- Only 5–30% of P applied as fertiliser is taken up by the plant in the year of application.
- P fertiliser is best applied at seeding.

Phosphorus (P) is an essential nutrient required for the growth of wheat with a key role in the structure of cell membranes, DNA and RNA, photosynthesis and respiration. Early plant growth is particularly dependent on adequate P due to its role in cell division. [32] Phosphorus is important in growing tissue where cells are actively dividing, i.e. seedling root development, flowering and seed formation. There must be sufficient plant-available N to get a response to P and there must be sufficient P for S and/or K responses to occur. Additive effects of N and P appear to account for most of the above-ground growth and yield response. [33] The symptoms of P deficiency are particularly evident during early growth stages. Mild P deficiency causes stunting while severe deficiency darkens leaves, causes older leaves to brown and die off and reduces tillering, head and grain numbers and slows crop development.

Soil testing should be conducted to determine phosphorus status. The phosphorus cycle in soil and plants is shown in Figure 2.

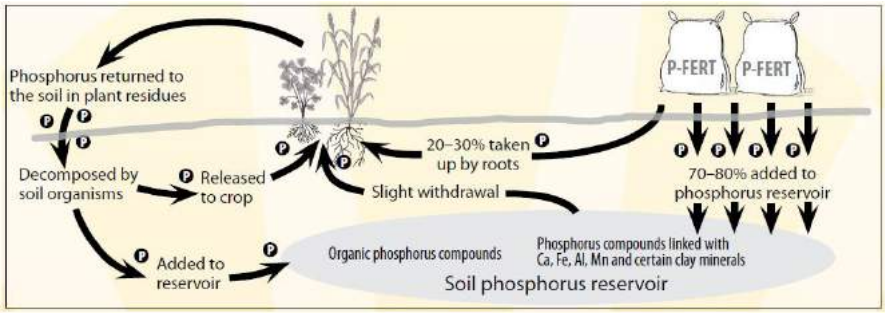


Figure 2: *The P cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited.*

From the Fertiliser Industry Federation of Australia Inc., 2000.

Source: Soilquality.org

In many soils of south-eastern Australia, P application has good residual value. However, if not applied for five to 10 years, even those soils with excellent fertiliser history are likely to develop a P deficiency.

In sandy soils P has a tendency to leach out of the soil. Sandy soils have been measured to lose up to 100% of applied P to leaching in the first season. Certainly 50% losses are common. Soils with sufficient levels of "reactive" iron (Fe) and aluminium (Al) will tend to resist P leaching. If you have sandy soils with low reactive levels of Fe and Al then you should test your P levels and apply less P more often, so that you don't lose your expensive P dollar to leaching. In soils with high free lime (10–20%), P will react with calcium carbonate in the soil to create insoluble calcium phosphates. Lock-up of P occurs on these soils at high pH and more sophisticated methods of applying P may be needed.

VIDEOS

Watch: GCTV13: Phosphorus uptake

MORE INFORMATION

Phosphorus as a nutrient for wheat in Southern Australia

32 CropPro Phosphorus as a nutrient for wheat in southern Australia. http://www.croppro.com.au/resources/Review%20-%20Phosphorus%20for%20wheat.pdf

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

5.6.1 Symptoms of phosphorus deficiency

Phosphorus deficiency is difficult to detect visually in many field crops, as the whole plant tends to be affected. Stunted growth, leaf distortion, chlorotic areas and delayed maturity are all indicators of phosphorus deficiency. Phosphorus is concentrated at the growth tip, resulting in deficient areas visible first on lower parts of the plant. A purple or reddish colour associated with accumulation of sugar, is often seen in deficient plants, especially when temperatures are low. Deficient cereal crops are often poorly tillered. Visual symptoms, other than stunted growth and reduced yield are not as clear as are those for N and K deficiencies. At some growth stages, P deficiency may cause the crop to look darker green. [34]

Paddock:

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header (Photo 3).
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf diseases.

Photo 3: *P deficient plants on the left are later maturing with fewer smaller heads.*

Source: DAFWA

Plant:

- In early development, usually in cases of induced P deficiency, seedlings appear to be pale olive green and wilted (Photo 4).
- On older leaves, chlorosis starts at the tip and moves down the leaf on a front, while the base of the leaf and the rest of the plant remains dark green. Unlike N deficiency, necrosis (death) of these chlorotic (pale) areas is fairly rapid, with the tip becoming orange to dark brown and shrivelling, while the remainder

34 R Quinlan, A Wherret. (2016). Phosphorus – Western Australia. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/phosphorus

turns yellow. At this stage the second leaf has taken on the early symptoms of P deficiency.

- By tillering, (uncommon) symptoms of severe deficiency are dull dark green leaves with slight mottling of the oldest leaf. [35]

Photo 4: *Stunted growth and yellowing of leaf tips in P deficient wheat (right).*

Source: Soil Quality Pty Ltd

5.6.2 Managing phosphorus

Key points

- After decades of consistent P application south eastern Australian soils, many soils now have adequate P status.
- Before deciding on a fertiliser strategy, use soil testing to gain a thorough understanding of the nutrient status across the farm.
- If the soil P status is sufficient, there may be an opportunity for growers to save money on P fertiliser by cutting back to a maintenance rate.
- Consider other factors: if pH ($CaCl_2$) is less than 4.5, the soil is water repellent or root disease levels are high, then the availability of soil test P is reduced and a yield increase to fertiliser P can occur even when the soil test P results are adequate.
- Work with an adviser to refine your fertiliser strategy.
- P reserves have been run down over several decades of cropping.
- Adding fertiliser to the topsoil in systems that rely on stored moisture does not always place nutrients where crop needs them.
- Testing subsoil (10–30 cm) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Applying P at depth (15–20 cm deep on 50 cm bands) can improve yields over a number of cropping seasons (if other nutrients are not limiting).
- Addressing low P levels will usually increase potential crop yields, so match the application of other essential nutrients, particularly N, to this adjusted yield potential. [36]

35 DAFWA (2015) Diagnosing phosphorus deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1996

36 GRDC (2012) Crop nutrition: Phosphorus management—Southern region Factsheet, www.grdc.com.au/GRDC-FS-PhosphorusManagement

MORE INFORMATION

Phosphorus in the South East Soils.

Crop nutrition: Phosphorus management – Southern region Factsheet

VIDEOS

WATCH: GCTV13: Phosphorus deficiency.

WATCH : Improving phosphate use efficiency

- Only 5–30 % of P applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus does not move readily in soils except in very light sandy soils in high rainfall areas. [37]

Long fallows due to crop rotation or drought may accentuate P deficiency through absence of mycorrhizae. Phosphorus fertiliser should be used in this situation. Where needed, apply P with the seed at planting. [38]

Place phosphorous with or near the seed at seeding time or band prior to seeding. High application rates can lead to both salt burning of the seedlings and a thin plant stand, reducing potential yield. [39]

Growers are encouraged to continue using starter P fertilisers at rates appropriate for the crop row spacing and soil moisture conditions at sowing. Applying small amounts of P in the seed row at sowing is offering excellent utilisation of the nutrient by the emerging crop. Yield increases with deep P application are dependent on a crops' ability to access and utilise the nutrient in the band. [40]

Soil testing

Testing of the P levels in your soil is important and will help in the budgeting of your P dollar.

Phosphorus is relatively immobile in soils and P applied to the 0 to 10 cm layer generally remains in that layer, especially in no-till systems. In most of our cropping systems, the Colwell-P soil test is still the benchmark soil P test used in Australia. The critical values differ between soil types, and the values given are expressed for the major soil types in south-eastern Australia. Soil critical P test value is not affected by wheat yield except where yields are very low (less than one tonne per hectare). On the highly calcareous soils (calcarosols), the DGT-P soil test provides a better prediction of crop response to fertiliser than Colwell-P. [41]

The release of P is related to:

- The total amount of P in the soil.
- The abundance of iron and aluminium oxides.
- Organic carbon content.
- Free Lime/ Soluble Calcium Carbonate.
- P Buffer Index (PBI).

Available P tests like the Colwell and Olsen's P test don't measure available P. Rather, they express an indication of the rate at which P may be extracted from the soils. This indicator of rate is calibrated with field trials. There is a relationship between Total Soil P and Colwell P and this can enable you to predict when a given level of P input (fertiliser) or output (product removal) will result in a risk of P rate of supply becoming a limiting factor. [42]

Sulfur

Sulfur (S) is an essential nutrient required for the growth of wheat and is a key element in the amino acids that form proteins essential for cellular structure and enzymes. Sulfur is also an essential part of proteins needed for pasta-making quality durum. The essential role of S in the formation of grain protein leads to grain protein being low when S is deficient.

37 R Quinlan, A Wherret. Phosphorus – Western Australia. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/phosphorus

38 DAFQ (2012) Durum wheat in Queensland. Queensland Department of Agriculture and Fisheries, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

39 Alberta Government (2016) Fall Rye Production, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

40 DW Lester, M Bell, R Graham, D Sands, G Brooke (2016) Phosphorus and potassium nutrition. GRDC Update Papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Phosphorus-and-potassium-nutrition

41 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

42 G Bailey, T Brooksby. Phosphorus in the South East Soils. Natural resources South East. Government of South Australia.

5.6.3 Symptoms of sulfur deficiency

Vegetative symptoms of S deficiency are stunting, yellowing of the whole plant and severe yellowing of the younger leaves when S deficiency is persistent. [43]

Paddock:

- Areas of pale or stunted plants (Photo 5).

Photo 5: *Areas of pale plants characterise Sulfur deficiency (NOTE: many other nutrient deficiencies also exhibit pale patches).*

Source: DAFWA

Plant:

- Plants grow poorly, lack vigour with reduced tillering, delayed maturity and lower yields and protein levels.
- Youngest leaves are affected first and most severely.
- Leaves on deficient plants leaves turn pale with no stripes or green veins but generally do not die and growth is retarded and maturity delayed (Photo 6).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red. [44]

43 CropPro (2013) Sulfur as a nutrient for agricultural crops in southern Australia. http://www.croppro.com.au/resources/Review%20Sulfur%2026082013.pdf

44 DAFWA (2015) Diagnosing sulfur deficiency in cereals. Department of Agriculture and Food Western Australia, July 2015, https://agric.wa.gov.au/n/1998

Photo 6: *Sulfur deficient wheat.*

Source: International Plant Nutrition Institute

Most soil S is in an organic form and not directly accessible to plants until undergoing mineralisation by micro-organisms. The rates of mineralisation and immobilisation are determined by soil water, temperature, pH and availability of other nutrients. As such, available S varies throughout the year with more mineralisation or organic S during warm, moist conditions and less during dry, waterlogged or cold conditions. Soils deficient in S are historically dominated by pasture production; namely Gippsland in Victoria, the tablelands in New South Wales, coastal regions with higher rainfall in SA, and northern coastal regions of Tasmania. [45]

Managing sulfur

Top-dressing 10–15 kilograms per hectare of S as gypsum or ammonium sulphate will overcome deficiency symptoms. [46]

Foliar sprays generally cannot supply enough S for plant needs. [47]

Historically, S has been adequate for crop growth because it is supplied in superphosphate, in rainfall in coastal areas and some from gypsum. In the southern region sulfur-responsive soils are uncommon in cereals. Sulfur inputs to cropping systems have declined with the use of triple superphosphate (TSP), mono-amomonium phosphate (MAP) and di-ammonium phosphate (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 impact on the ability of the

45 CropPro (2013). Sulfur as a nutrient for agricultural crops in southern Australia. http://www.croppro.com.au/resources/Review%20Sulfur%2026082013.pdf

46 DAFWA (2015) Diagnosing sulfur deficiency in cereals. Department of Agriculture and Food Western Australia, July 2015, https://agric.wa.gov.au/n/1998

47 DAFWA. Diagnosing Sulfur deficiency in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-sulfur-deficiency-cereals

soil S test to predict plant available S. Interrogation of wheat trial data in the GRDC's 'Making better fertiliser decisions for cropping systems in Australia' project database found that the critical soil S test value (measured in the 0 to 10 cm soil layer) is poorly defined when considered across all soil types. [48]

5.7 Potassium

Key points:

- Soil testing combined with plant tissue testing is the most effective means of determining Potassium (K) requirements.
- Banding away from the seed, at or within 4 weeks of sowing, is the most effective way to apply K when the requirement is less than 15 kg/ha.
- Sandy soils in high rainfall areas are prone to K deficiency.
- Soil testing is the most effective means of determining K requirements.
- Deficiency symptoms first occur in the older leaves, and can be mistaken for disease infections.
- Potassium export during harvest must be accounted for when calculating nutrient budgets.

Potassium (K) is one of the essential nutrients in plants. It has many functions including the regulation of the opening and closing of stomata, which are the breathing holes found on plant leaves and therefore regulate moisture loss from the plant.

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 about 40 mg/kg on chromosols, to about 49 mg/kg on kandosols and about 64 mg/kg on brown ferrosols. There is some evidence that critical values increased with increasing crop yield and on soils with no acidity constraints to root growth. [49]

5.7.1 Symptoms of potassium deficiency

Potassium is highly mobile in the phloem and can be moved to newer leaves if the nutrient is in short supply, with deficiency symptoms appearing first on older leaves. [50]

Paddock:

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows (Photo 7).
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease. [51]

48 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

49 GRDC (2014) Soil testing for crop nutrition (southern region). Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/GRDC-FS-SoilTestingS

50 R Quinlan, A Wherret. (2016). Potassium. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/potassium

51 DAFWA (2015) Diagnosing potassium deficiency in wheat. Department of Agriculture and Food Western Australia, April 2015, https://agric.wa.gov.au/n/1997

Photo 7: *Header rows have fewer potassium deficiency symptoms.*

Source: DAFWA

Plant:

- Plants appear paler and weak.
- Older leaves are affected first with leaf tip death and progressive yellowing and death down from the leaf tip and edges. There is a marked contrast in colour between yellow leaf margins and the green centre (Photo 8).
- Yellowing leaf tip and leaf margins sometimes generates a characteristic green 'arrow' shape towards leaf tip. [52]

52 DAFWA (2015) Diagnosing potassium deficiency in wheat. Department of Agriculture and Food Western Australia, April 2015, https://agric.wa.gov.au/n/1997

Photo 8: *Plants affected by K deficiency may be paler, weaker and more susceptible to leaf disease. Discouloured leaf tissue can be bright yellow.*

Source: Department of Agriculture and Food Western Australia

5.7.2 Managing potassium

Top-dressing K will generally correct the deficiency. Foliar sprays generally cannot supply enough K to overcome a severe deficiency and can also scorch crops. [53]

Banded K has been shown to be twice as accessible to the crop as top-dressed K. This is thought to be related to improved availability for the emerging crop, and decreased availability for weeds. Growers should not band high rates (i.e. >15 kg/ha) particularly with sensitive crops and should try to place K fertilisers away from the seed. Furthermore, growers should be aware that nutrient auditing requires fertiliser applications to cover K export during harvest, and are encouraged to account for variations in yield where possible.

If a paddock is severely deficient then K needs to be applied early in the season to maximise response to the application. At seeding or up to four weeks after will optimise the benefits of K application. [54]

Assessing potassium requirements

Soil and plant tissue analysis together give insight into the availability of K in the soil. Growers should not rely on soil testing alone as results are subject to many potential sources of error.

53 DAFWA. Diagnosing potassium deficiency in wheat, https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-wheat

54 R Quinlan, A Wherret. Potassium. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/potassium

Tissue analysis of whole tops of crop plants will determine whether a deficiency exists but doesn't define a K requirement. These results are generally too late to be useful in the current season, but inform the need to assess K requirements for the next crop.

K available in the soil is measured by the Colwell K or Exchangeable K soil tests. The amount of K needed for plant nutrition depends on soil texture (Table 5).

Table 5: *Critical (Colwell) soil test thresholds for K (ppm).*

	Deficient	Moderate	Sufficient
Cereal, canola, lupins etc. (Brennan & Bell 2013)	< 50	50–70	> 70
Pasture legumes (Gourley et al. 2007)	< 100 (sand) <150 (clay loam)	100-140 (sand) 150-180 (clay loam)	> 140 (sand) > 180 (clay loam)

Source: Soilquality.org

Sandy soils require less K to be present, but are more likely to show deficiencies. Clay soils require more K to be present, but are more capable of supplying replacement K through the weathering of clay minerals.

K lost through product removal should be replaced once paddocks fall below sufficient K levels, rather than waiting for deficiency symptoms to appear. Replacement requirements for each crop differ, and this must be accounted for when budgeting K requirements for the coming season.

Fertiliser types

Sulphate of potash (SOP—potassium sulphate) is usually recommended if K is deficient. Applying the cheaper muriate of potash (MOP—potassium chloride) also corrects K deficiency, but it also adds chloride to the soil, which contributes to overall salinity and can decrease the establishment of seedlings.

Potassium magnesium sulphate can also be used where magnesium and sulphate are also required. This form is often used in "complete" fertiliser blends. Potassium nitrate supplies N and K in a highly water soluble (and available) form, but is rarely used in broadacre farming because of its cost.

Fertiliser placement and timing

K generally stays very close to where it is placed in the soil. Banded K has been shown to be twice as accessible to the crop as top-dressed K. This is thought to be related to improved availability for the emerging crop, and decreased availability for weeds. Seed must be sown within 50 mm of the K drill row or seedlings may miss the higher levels of K. If a paddock is severely deficient then K needs to be applied early in the season, at seeding or up to 4 weeks after. [55]

5.8 Micronutrients

Key points:

- Micronutrients or trace elements most likely to be out of balance in southern Australian durum cropping soils are zinc, copper and manganese.
- Trace elements are important in particular situations but are not miracle workers.
- Deficiencies are not uncommon, but when they occur can give large yield penalties.

55 Soilquality.org. Potassium—NSW, http://www.soilquality.org.au/factsheets/potassium-nsw

- Diagnosis by soil test and tissue test is difficult, but in most cases, the potential for deficiencies can be assessed by reviewing soil types, crop type and seasonal conditions.
- Products vary in their efficiency and growers should look for evidence for the efficacy of products in their region.

Essential trace elements are nutrients which are required by plants and animals to survive, grow, and reproduce but are needed in only minute amounts. Southern Australian cropping soils are more likely to be deficient in zinc (Zn), copper (Cu), and manganese (Mn) than the other trace elements.

Of these three, Zn deficiency is probably the most important because it occurs over the widest area. Zn deficiency can severely limit annual pasture legume production and reduce cereal grain yields by up to 30 per cent. Cu deficiency is also important because it is capable of causing total crop failure.

If these three trace elements are not managed well the productivity of crops and pastures can suffer valuable losses, and further production can also be lost through secondary effects such as increased disease damage and susceptibility to frost.

Adequate trace element nutrition is just as important for vigorous and profitable crops and pastures as adequate major element (such as nitrogen or phosphorus) nutrition.

Many soils in the cropping zone of southern Australia are deficient in trace elements in their native condition. Despite many decades of research into trace element management, crops can still be found to be deficient in one or more of these trace elements. Just because trace element deficiencies have not been prevalent in recent years, does not mean they will not return.

There is increasing concern in some districts that trace element deficiencies may be the next nutritional barrier to improving productivity. This is because current cropping systems are exporting more nutrients to the grain terminal than ever before. [56]

Most growers and agronomists are fully aware of the nitrogen and phosphorus demands of crops, and meeting those demands is a major investment in crop production. Sulfur and potassium are also important in some regions as are calcium and magnesium. These six nutrients, the macronutrients, are complemented by a set of nutrients required in smaller amounts; the micronutrients or trace elements. Even though needed in small quantities, Copper (Cu), Manganese (Mn), Iron (Fe), Zinc (Zn), Boron (B) and Molybdenum (Mo) are all essential for plant growth, although the demand is small relative to nitrogen and phosphorus.

South Australia has a long history of micronutrient research, and in the early 1960s it was found that foliar sprays of Mn onto barley gave a 20-fold yield response in the southern Yorke Pennisula. This was the first time foliar trace elements had been applied to agricultural crops in Australia. Similarly, with copper, South Australian scientists have led the way with diagnosis and remediation, as well as developing a deep understanding of cultivar differences in copper (and manganese) responses. Even so, between farms and within farms, the response to micronutrients will differ. [57]

5.8.1 Zinc

Compared to bread wheats, durum wheats can be sensitive to low zinc (Zn) levels. Crops usually tolerate low Zn levels when grown on heavy, self-mulching black earths (pHCa 8–8.5). Elongated necrotic lesions (dead patches) on the lower leaves may indicate the onset of Zn deficiency. When a crop is growing in a very wet, high-phosphate soil for several weeks, Zn deficiency symptoms may be evident. [58]

MORE INFORMATION

GRDC Update Papers: Detecting and managing trace element deficiencies in crops.

GRDC Update Papers: Trace elements; copper and manganese – their role, requirements and options.

Trace element disorders in South Australian Agriculture

56 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Detecting-and-managing-trace-element-deficiencies-in-crops

57 Norton R. (2014). GRDC Update Papers: Trace elements; copper and manganese – their role, requirements and options. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Trace-elements-copper-and-manganese-their-role-requirements-and-options

58 Hare R. (2006). Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

Symptoms of zinc deficiency

Paddock:

- Patchy growth of stunted plants with short thin stems and usually pale green leaves.
- Heavily limed soils, sands and gravels or alkaline grey clays tend to be most affected.
- Zinc deficiency symptoms are usually seen on young seedlings early during the growing season.

Plant:

- Young to middle leaves develop yellow patches between the mid-vein and edge of the leaf and extend lengthways towards the tip and base of the leaf. This stripe may occur only on one side of the mid-vein.
- The areas eventually die turning pale grey or brown.
- The leaf changes from green to a muddy greyish-green in the central areas of middle leaves.
- Stunted plants often have 'diesel-soaked' leaves, showing dead areas about halfway along the leaves, causing them to bend and collapse in the middle section (Photo 9).
- Maturity is delayed. [59]

Photo 9: *Plants affected by Zn deficiency may show necrosis half way along middle and older leaves, causing them to droop.*

Source: Department of Agriculture and Food Western Australia

59 DAFWA (2015) Diagnosing zinc deficiency in wheat. Department of Agriculture and Food Western Australia, June 2015, https://agric.wa.gov.au/n/1999

Management strategies

If the soil is known to be low in Zn (soil and plant tissue tests are available), a 1% aqueous solution of zinc sulfate heptahydrate applied as a foliar spray two to four weeks after emergence ameliorates the deficiency at about 1 kg/ha. Zinc sulfate monohydrate applications can provide 4–5 years supply of this essential micronutrient. Apply at 15 kg/ha on sandy and sandy-loam soils, or 30 kg/ha for clay and clay-loam soils and incorporate some months before sowing. Where P fertilisers are required, products that are coated with Zn provide a very efficient method of increasing crop recovery of applied Zn. Note that zinc oxide (5 kg Zn/ha) applications can be spread with N fertilisers but not with P fertilisers, as the P can bind with the Zn and render it unavailable. A range of zinc-fortified starter fertilisers are also available. [60]

- Zinc can be applied via foliar spray (effective only in current season) or drilled soil fertiliser.
- Zinc foliar sprays need to be applied as soon as deficiency is detected to avoid irreversible damage.
- As Zn is immobile in the soil, topdressing is ineffective, only being available to the plant when the topsoil is wet.
- Mixing Zn throughout the topsoil improves availability due to more uniform nutrient distribution.
- Zinc drilled deep increases the chances of roots being able to obtain enough Zn when the topsoil is dry.
- Zinc seed treatment is used to promote early growth where root disease is a problem, but the level is lower than a plant needs in the current season.
- Zinc present in compound fertilisers often meets the current requirements of the crop.

5.8.2 Copper

Copper (Cu) is essential for pollen formation and has a role in formation of chlorophyll and lignification (cell wall strength). Deficiency causes sterile pollen which, in turn, causes poor grain formation and high yield losses. [61]

Symptoms of copper deficiency

Paddock:

- Before head emergence deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green healthy crop.
- After head emergence mildly affected areas have disorganised wavy heads. Severe patches have white heads and discoloured late maturing plants.
- Symptoms are often worse on sandy or gravelly soils, where root pruning herbicides have been applied and recently limed paddocks.

Plant:

- Youngest growth is affected first.
- First sign of Cu deficiency before flowering is growing point death and tip withering, and/or bleaching and twisting up to half the length of young leaves (Photo 10).
- Base of the leaf can remain green.
- Old leaves remain green, but paler than normal.
- Tiller production may increase but die prematurely.
- Mature plants are dull grey-black in colour with white or stained empty or 'rat-tail' heads.

60 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

61 DAFWA (2015) Diagnosing copper deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1990

- Grain in less severely affected plants may be shrivelled. Heads with full grain droop due to weak stems. [62]

Photo 10: *Plants affected by Cu deficiency may have partly sterile heads and twisted flag leaves.*

Source: Department of Agriculture and Food Western Australia

Managing copper

- Copper can be applied as a foliar spray (only effective in the current season) or drilled soil fertiliser.
- Copper foliar sprays are not effective after flowering as sufficient Cu is required pre-flowering for pollen development.
- Mixing Cu throughout the topsoil improves availability due to more uniform nutrient distribution.
- As Cu is immobile in the soil, topdressing is ineffective, only being available to the plant when the topsoil is wet.
- In long term no-till paddocks frequent small applications of Cu via drilled or in-furrow application reduces the risk of plant roots not being able to obtain the nutrient in dry seasons.
- Copper drilled deep increases the chances of roots being able to obtain enough copper when the topsoil is dry.
- Copper seed treatment is insufficient to for plant requirement in the current season. [63]

5.8.3 Boron

Boron (B) is essential for crop growth and development but in very small quantities. While the precise role of boron in plants is not fully known there is evidence to show that boron is important for cell division, the production of nucleic acids (DNA, RNA), the movement of sugars across membranes and the development of reproductive structures (i.e. pollen tubes, fruit, grain).

62 DAFWA (2015) Diagnosing copper deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1990

63 DAFWA (2015) Diagnosing copper deficiency in wheat. Department of Agriculture and Food Western Australia, May 2015, https://agric.wa.gov.au/n/1990

Symptoms of boron deficiency

Paddock:

- Sandier, more acidic parts of the paddock will be most affected.

Plant:

- Symptoms appear first on the youngest leaf and gradually spread to older growth.
- First sign of boron (B) deficiency is leaf splitting close to the mid rib accompanied by saw tooth notches along the leaf edge (Photo 11).
- In severe cases tillering increases, shoots wither and new leaves die back from tip. [64]

Photo 11: *Plants affected by B deficiency may show saw tooth notches on leaf edge (left) and withering of emerging shoot (right).*

Source: Department of Agriculture and Food Western Australia

Boron toxicity

Boron toxicity is usually an inherent feature of a soil and is a particular problem when high boron levels occur in the subsoil.

What to look for:

Paddock:

Symptoms mostly occur in spring and are identical to those in drought affected plants.

Plant:

Symptoms appear first and most severely on the oldest leaves.

Leaf tip death progressing from the tip and margins.

In severe cases, yellow spotting occurs lower down on older leaves.

Managing boron

- Boron can be applied via soil or foliar applications of B.

64 DAFWA (2015) Diagnosing boron deficiency in wheat. Department of Agriculture and Food Western Australia, April 2015, https://agric.wa.gov.au/n/1988

- Soil applications generally last longer but can be leached from acidic, sandy soils. Avoid using higher rates than necessary as these can cause B toxicity in plants.
- Foliar applications act rapidly but timing of application is important to avoid irreversible damage. [65]

IN FOCUS

Nutrient uptake and distribution by bread and durum wheat under drought conditions in SA

An important limitation to the production of durum wheat in SA is its poor adaptation to the alkaline, sodic soils of the cereal belt, which often results in nutrient imbalances in the crop. A field experiment was conducted at Palmer, SA, to measure the nutrient uptake and distribution between grain and straw of three bread wheat cultivars and nine cultivars and breeding lines of durum wheat. The purpose of the work was to characterise the patterns of nutrient uptake and to examine whether there were major, consistent differences between bread wheat and durum wheat. Rainfall during the growing season was below average and the crops suffered from drought stress after anthesis. Plants were marginally deficient or deficient in N, P and Zn, and B concentrations were high. Compared with bread wheat, durum wheat had a very much higher concentration of sodium (Na), higher concentrations of calcium (Ca) and S, but lower concentrations of K, magnesium (Mg), manganese (Mn) and Cu. Total amounts of P, Zn and Na in the shoot continued to increase throughout the growing season with significant increases occurring during grain filling, whereas there was little increase in the amount of N, K, B and Mn during grain filling. The maximum rate of nutrient uptake occurred before the time of maximum crop growth rate, and was in the order K (10.1 weeks after sowing), N (10.6), P (11.3), Mn (12.0), Zn (12.5) and B (14.6); maximum growth rate occurred at 14.8 weeks. There was no consistent difference between bread and durum wheat in the partitioning of nutrients to the grain. The importance of N and Zn uptake to the growth of the durum wheat genotypes was shown by significant correlations between maximum uptake rates of these nutrients and maximum crop growth rate, with the strongest correlation being with Zn. Growth rate was not correlated with uptake rates of other nutrients. A number of genotypes of durum wheat had maximum rates of Zn and Mn accumulation up to twice those of the current commercial genotypes. Some of these lines have yielded well at Zn- and Mn-deficient sites which indicates that the micronutrient efficiency of durum can be improved. Late in the season the experiment showed signs of infection by crown rot (*Fusarium graminearum* Schw. Group 1). Durum wheat showed more severe symptoms than bread wheat and the number of white heads in durum wheat was inversely correlated with the concentration of Zn in the shoot during the pre-anthesis period. [66]

65 DAFWA (2015) Diagnosing boron deficiency in wheat. Department of Agriculture and Food Western Australia, April 2015, https://agric.wa.gov.au/n/1988

66 A Zubaidi, GK McDonald, GJ Hollamby (1999). Nutrient uptake and distribution by bread and durum wheat under drought conditions in South Australia. Animal Production Science, 39(6), 721–732, http://www.publish.csiro.au/paper/EA98185.htm

5.9 Paddock nutrition

It is not uncommon for paddocks to have multiple nutrition deficiencies, or variations in nutritional requirements, even with a similar cropping history. Paddock history, past crop performance, fertiliser test strips and soil tests can help to determine the most appropriate decision about subsequent crop management. Fertiliser is a major cost. Fertiliser rates to meet crop requirements may be modified if residual fertiliser from the last season remains.

FAQ

Weed control

Key messages

- Good weed control is essential, as weeds compete with crops for available moisture and nutrients, causing yield reduction (Photo 1).
- Varieties differ in their ability to compete with weeds.
- Durum has typically been a poor competitor with weeds, but the durum varieties DBA Aurora(Ɒ and Saintly(Ɒ show similar weed competitiveness to the wheat variety Mace. Weed-competitive varieties are a useful weed management tool.
- Knowing which weeds are in the paddock and where the weed seeds are located (shallow or deep) is important in selecting a herbicide program.
- Durum wheats can be more sensitive to some herbicides that are commonly and safely used in bread wheat.
- Knowledge of a product's ability to be translocated within the weed and formulation type is important for selecting nozzles and application volumes.
- Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical. Also consider the growth stage of the crop, the crop variety being grown and its herbicide tolerances.
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought. This is especially pertinent for frosts with grass weed chemicals.

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

Photo 1: *A ryegrass head in a wheat crop.*

Photo: Nicole Baxter, Source: GRDC.

6.1 Integrated weed management

The Grains Research and Development Corporation (GRDC) supports integrated weed management.

Download the Integrated Weed Management Manual.

1 GRDC (2014) Integrated weed management hub. GRDC, https://grdc.com.au/weedlinks

Integrated weed management (IWM) is a system for managing weeds over the long term, particularly the management and minimisation of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given that there are additional costs associated with implementing IWM, the main issues for growers are whether it is cost-effective to adopt the system and whether the benefits are likely to be long-term or short-term in nature.

The IWM manual looks at these issues and breaks it down into seven clear sections, assisting the reader to make the development of an IWM plan a simple process.

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

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

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

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

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

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

6.1.1 IWM tactics

- Controlling small weeds
- Stop weed seed set
- Reduce weed seed numbers in the soil
- Hygiene - prevent weed seed introduction
- Agronomic practices and crop competition

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

There are several agronomic practices that improve crop environment and growth, along with the crop's ability to reduce weed competition. These include crop choice and sequence, improving crop competition, planting herbicide tolerant crops, improving pasture competition, using fallow phases and controlled traffic or tramlining. [2]

Review past actions

Knowing the historical level of selection pressure can be valuable information to give managers a 'heads up' as to 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

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

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 MOA's 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, using 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 sub divide these into broadleaved and grass weeds.

Account for double knocks. Where survivors of one tactic would have been controlled in large part by the use of another tactic, reduce the number of MOA uses accordingly. An example might be: Trifluralin has been used 20 times, but there have been 6 years when in-crop Group A selectives were used and several more years where in-crop group B products that targeted 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 somewhat.

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 be 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.

Table 1: *Typical number of years of use to develop resistance MOA groups.*

Herbicide Group	Typical years of application	Resistance risk
A (fops/dims/dens)	6–8	High
B (SU's, IMI's)	4	High
C (triazines, subst. ureas)	10–15	Medium
D (trifluralin, Stomp)	10–15	Medium
F (diflufenican)	10	Medium
I (phenoxies)	>15	Medium
L (paraquat/diquat)	>15	Medium
M (glyphosate)	>12	Medium

Source: DAFWA

Assess the current weed status

Record the key broadleafed 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.

Identify weed management opportunities within the cropping system

Identify what different herbicide and non-herbicide tactics could be cost effectively added to the system and where in the crop sequence these can be added. For information on the different integrated weed management tactics, see IWM: Section 4: Tactics for managing weed populations.

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 seed bank?

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 being used are the "Weed Seed Wizard" and RIM – Ryegrass Integrated Management.

Combine ideas using a rotational planner, or test them in using decision support software such as RIM &/ or Weed Seed Wizard.

IN FOCUS

Weed Seed Wizard

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

It 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, 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.

MORE INFORMATION

Weed seed wizard

South Australian Weed Control App

The free Weed Control app provides essential information about the control of weeds declared in South Australia under the Natural Resources Management Act 2004.

The weed control app includes:

- control recommendations for over 132 declared plants
- chemical and non-chemical treatments
- information on the safe use of herbicides
- colour photographs of each species for identification

The Weed control app provides information from the Weed Control Handbook for Declared Plants in South Australia.

In addition app users can:

- record the location of weeds

MORE INFORMATION

Weed control handbook for declared plants in South Australia.

Declared plants in SA – are they on your land?

SA weed risk management guide.

- keep a personal log of control activities
- phone or email regional Natural Resource officers
- send photos and text of high risk weeds

The app will be updated annually as chemical uses and plant declarations change.

The SA Weed Control app is produced by Biosecurity SA in partnership with the eight Natural Resource Management regions.

Download app from Google Play (for Android devices) or iTunes App Store.

6.1.2 Improved grass weed control in durum

Durum wheat is an inherently poor competitor with grass weeds and requires an increased reliance on herbicide use coupled with good agronomic practices (i.e. paddock selection). There are limited safe and effective herbicide options for grass weed control in durum. The introduction of new pre-emergent chemistry for managing resistant ryegrass populations has been welcomed by industry. However, BoxerGold® and Avadex® are the only registered pre-emergent options for durum, and both these herbicides still present some issues in durum as they have potential to cause significant crop damage resulting in reductions in plant establishment, early vigour and yield. Furthermore, ryegrass can still set large amounts of seed even if it has been treated with a pre-emergent herbicide. It is therefore prudent for growers to integrate other strategies to help improve a crop's competitive ability with weeds. A project aiming to improve grass weed control in durum wheat was led by the SA Durum Growers Association. Trials in 2012 demonstrated that the management combination of variety, seeding rate, and herbicide all play a significant role in the success of the system (Figure 1). [3]

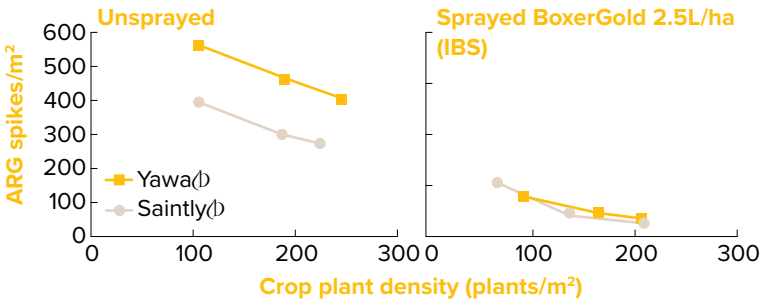


Figure 1: *The effect of management combination of variety, herbicide and plant density on the density of annual ryegrass spike at Tarlee, 2012 (LSD 5% = 55 spikes/m²).*

Source: SA Research and Development Institute

Key messages from research in durum wheat in South Australia:

- In Mace wheat and DBA Aurora durum, increasing crop seeding rate reduced ryegrass head set and decreased screening percentage.
- Durum varieties Saintly and DBA Aurora showed they had a similar ability to reduce ryegrass seed set through competition when compared to Mace wheat.
- DBA Aurora and Saintly were the best choices of durum variety for weed competitiveness.
- Varying seeding rates can change the amount of crop yield loss under high weed pressure.

3 K Porker, R Wheeler (2012) Improving grass weed control in durum. SA Research and Development Institute, http://midnorthhighrainfall.org.au/wp-content/uploads/2014/08/0012IWM-durum-article.pdf

MORE INFORMATION

A new approach to grass weed control for durum wheat.

- Sakura® is unlikely to be registered for use in durum as it shows high levels of crop damage.
- Although some initial damage can occur, a package combining higher seeding rates, large seed size and Boxer Gold® were the best available chemical and agronomic practices for pre-emergent weed control. [4]

6.1.3 IWM in Southern Region

Grain growers in Victoria, South Australia and Tasmania have the ability to beat costly weeds by driving down the weed seed bank through an aggressive 'stacked' approach.

By combining five essential measures and repeating the exercise year after year, growers can run down seed banks even when experiencing high levels of herbicide resistance on their farms.

Very high weed seed banks can be eroded to low, near-zero levels by committing to a simple strategy.

The five components of a successful strategy are:

1. a double knock of herbicides;
2. mixing and rotating chemicals;
3. competitive crops;
4. stopping seed set; and
5. harvest weed seed control.

When you stack all these components together, you can drive down the weed seed bank.

Double knock is not so much about the seed bank but preserving glyphosate. If you double knock every year glyphosate resistance shouldn't be an issue. But it's not a double knock if you already have glyphosate resistance. If you have lot of glyphosate resistance and you start double knocking, you are basically applying a single knock of paraquat, and paraquat resistance will happen. The best time to start using double knock is before you have glyphosate resistance.

It's also important to have mixed herbicide use. By mixing two herbicides together at full rates, if a weed is resistant to one product the other will kill it before it sets seed, as it is almost impossible for a weed to have two resistance mechanisms before herbicide selection.

Crop competition involves four aspects—seeding rate, row spacing, orientation and cultivars. Growers need to be doing at least one of these things, preferably two, in terms of encouraging crop competition.

The fifth component is harvest weed seed control (HWSC), which has been a focus of AHRI's research and development efforts. In mixed farming systems with sheep, using a chaff cart for HWSC is recommended. For continuous croppers in high production areas, the Harrington Seed Destructor is recommended. Putting chaff on tramlines is cheap and there is nothing to do after harvest. Chaff lining is another option, leaving it in the windrow to rot. Windrow burning is a popular option, with more people windrow burning than any other HWSC activity, but it does have its problems. With the other HWSC tools growers can do them in every crop every year, but that's not always the case with windrow burning.

The sixth tool is bale direct, which involves towing a baler behind the harvester. This is a good option where a large market for straw bales exists close to the farm.

Competitive crops improve HWSC. Competitive crops hold the ryegrass and other weeds up so that growers can catch them in the header. HWSC works better on low-density ryegrass.

4 SAGIT (2015). SAGIT research snapshot. DG1202: A new approach to grass weed control for durum wheat. http://www.sagit.com.au/wp-content/uploads/2014/07/ResearchSummary_DG1202_A-new-approach-to-durum-weed-control.pdf

VIDEOS

WATCH: Over the Fence: IPM delivers 'unexpected' pest control benefits.

A lot of weeds are becoming more dormant. They are adapted to germinate later to avoid knock-down and pre-emergent herbicides. Ryegrass, barley and brome grasses are germinating later. But it is an advantage because it means growers can sow a competitive crop early and compete with the weeds.

When all components of weed seed management are stacked together and growers commit to the regime for at least six years, the outcome can be dramatic. [5]

6.1.4 Ryegrass management in the Southern Region

Herbicide resistance is on the increase, with higher levels of chemical tolerance recorded in south-east South Australia.

In 2013, a study found that 16 % of paddocks in the south-east contained glyphosate-resistant ryegrass (Photo 2).

Photo 2: *Glyphosate resistant ryegrass in crop paddock.*

Source: Weekly Times

While herbicide resistance is widespread across Australia, a three-year trial by the University of Adelaide at Roseworthy in SA's mid-north found strategic use of oaten hay was the best tool for rapidly reducing the seedbank of annual ryegrass. However, another year of seed-set control is vital for keeping populations low.

Three different weed management strategies were used for ryegrass control in a four-year trial for improving weed management.

Cutting oaten hay in the first year reduced the seedbank of ryegrass by 86 %, from 4819 seeds/m^2 to 692 seeds/m^2 in one year.

Field peas were sown in the following year and three spray options used across three sections.

- When trifluralin was used alone, seedbank levels increased from 692 seeds/m^2 to 8319 seeds/m^2.
- When Select® was applied after trifluralin, the ryegrass seedbank slightly increased from 692 seeds/m^2 to 806 seeds/m^2.
- When Select® was applied and the field peas crop-topped with Roundup® glyphosate, the seedbank declined to less than 500 seeds/m^2.

This shows the importance of that second year of seed-set control in managing annual ryegrass.

5 S Watt (2016) Odds of beating weeds stacked in favour of grain growers, https://grdc.com.au/Media-Centre/Media-News/South/2016/03/Odds-of-beating-weeds-stacked-in-favour-of-grain-growers

Growers need to be cautious in chemical use because resistance to Select® is on the increase in SA, which is a major concern given the herbicide's importance for providing effective control of ryegrass in pulse and canola break crops.

Crop-topping after Select® application, even if there are only a few weeds left in the paddock, decreased the risk of resistance emerging.

Where two years of seed-set control had been used, the annual ryegrass seedbank in the following wheat crop continued to decline, even where Boxer Gold® was the only herbicide used. [6]

From 2012, a trial at SFS' Lake Bolac site, which has a history of resistant ryegrass, assessed the effectiveness and applicability of cultural control practices before seeding, in combination with pre-emergent herbicides on management of herbicide-resistant annual ryegrass in the Victorian HRZ.

The cultural control practices include mouldboard ploughing, stubble burning, stubble incorporation with light cultivation and retained stubble with direct sowing. These were followed up with low cost (such as trifluralin mixtures), medium cost and high cost (such as Sakura + Avadex Xtra mixtures in wheat) pre-emergent options.

Lessons learnt from the trial so far include:

Mouldboard ploughing

Although expensive, early results from mouldboard ploughing were promising, despite some wild radish germinating in the area ploughed.

In a long-season scenario where there is plenty of rain, any ryegrass that is germinating late after treatments have been applied will produce a lot of seed. In the HRZ it is a problem. If growers are not stopping the seed set of ryegrass it will reset the seedbank pretty quickly.

Pre-emergent herbicides

The biggest lesson learned from using pre-emergent herbicides was to not incorporate stubble.

If you have too much stubble and you want to get rid of it, burn it. Incorporating stubble moves the ryegrass away from where the herbicides are applied, limiting their effectiveness.

If you have post-emergent resistant ryegrass and you think you are going to manage your way out of that by growing wheat and barley, it's not going to happen. Even with best treatments, numbers are still going up.

Unsurprisingly, the cheapest pre-emergent herbicide strategies were the least effective. The mid-cost strategy is better but the expensive strategy is best.

In the cereal side of your rotation, if you really want to keep a lid on the ryegrass you're going to have to go for some pretty expensive herbicide options to do that in the HRZ. A lot of that is about needing the length of persistence we get out of that product, particularly the Sakura® + Avadex® Xtra mix.

Narrow windrow burning

When attempting to windrow burn barley in these trials the burn got too fast and didn't burn the windrows all the way down to the ground, leaving streaks of ryegrass across the site.

The lesson there is that if you're going to windrow burn, don't start practising with barley because it's probably the hardest crop to do it in. Start with something easy like canola. Learn how to do it and do it well. [7]

MORE INFORMATION

Ryegrass Integrated Management

VIDEOS

WATCH: Managing herbicide resistant ryegrass with IWM.

6 D Lush (2013) Consistent weed control needed to combat ryegrass, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-106-Sept-Oct-2013/Consistent-seed-control-needed-to-combat-ryegrass

7 A Lawson (2015) HRZ trial yields lessons in resistant ryegrass management, https://grdc.com.au/Media-Centre/Media-News/South/2015/01/HRZ-trial-yields-lessons-in-resistant-ryegrass-management

6.1.5 Brome and barley grass in the Southern Region

Control of brome grass is becoming increasingly difficult throughout south-eastern Australia's cropping zone due to high herbicide resistance, increasing seed dormancy and spread of the weed from its traditional low rainfall area to new regions (Photo 3).

Increasing incidence of brome and barley grass in cropping paddocks in southern Australia is likely to be associated with selection of more dormant biotypes by weed management practices used by the growers.

At present, brome grass management in cereals is heavily reliant on Group B herbicides, especially the Clearfield™ technology. Delaying onset of resistance to these herbicides would require identification of effective alternative herbicides.

Photo 3: *Brome grass growing in a cereal crop at a University of Adelaide trial at Balaklava.*

Source: GRDC

Field trials undertaken over four years have investigated various pre-emergence herbicides for brome grass control in wheat. Even though Sakura® (pyroxasulfone) appears to be the most active pre-emergence herbicide against brome grass, it lacks consistency required for long-term population management of brome grass.

Surveys by the University of Adelaide in a previous GRDC-funded project showed high levels of resistance to Group B herbicides, with 40–50% resistance to Atlantis® and Crusader™ in the South Australian Mallee, and 40% resistance to Atlantis® in Victoria.

Field trials over four years confirmed consistently high efficacy of Sakura® against barley grass, especially under situations with good soil moisture.

Barley grass management is now being complicated by evolution of group A resistance in this weed species. However, there appear to be several effective alternatives (e.g. Sakura® and Raptor®) that could be used for barley grass control in broadleaf crops. [8]

8 G Gill, L Shergill, B Fleet, P Boutsalis, C Preston (2013) Brome and barley grass management in cropping systems of southern Australia, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Brome-and-barley-grass-management-in-cropping-systems-of-southern-Australia

Pre-emergent control options are no more promising because most common options are ineffective. The most common practice in wheat is use of trifluralin, but trials have shown trifluralin may only provide about 50% control in wheat. The combination of Sakura® and Avadex® has been shown to be more effective, but the high cost means it is often uneconomical.

With herbicide control providing no easy solutions, an integrated weed management strategy is needed to control the problem weed.

Where there are severe brome patches in cereals, in the range of >50 plants/m^2, it is recommended that growers patch out the area with a knockdown herbicide such as glyphosate before it can set seed. Where the soil type permits, narrow windrow burning can be a good control method, or else options such as chaff carts can help reduce the seedbank.

However, the most effective control will be to use rotations. For a severe infestation, use a pulse or break crop with a grass selective herbicide and crop-topping, followed by a Clearfield variety using Imidazolinone (imi) chemistry. If there are still some weeds after two years, go to barley with trifluralin and metribuzin for a third-step control.

Full results from the trials are expected in 2017. [9]

Barley grasses (*Hordeum* spp) are annual species renowned for rapidly germinating in autumn to provide valuable stock feed soon after season-opening rains (Photo 4). This speedy establishment has traditionally been seen as a useful clue for early identification, but changes in seedbank dormancy now mean an increasing proportion of the seedbank is germinating later in the season.

Photo 4: *Seedling of barley grass (Hordeum leporinum).*

Photo D. Holding. Source: GRDC

MORE INFORMATION

Brome and Barley grass management in Southern cropping systems.

Long-term strategy needed for brome grass control.

9 R Barr (2014) Long-term strategy needed for brome grass control, https://grdc.com.au/Media-Centre/Media-News/South/2014/10/Long-term-strategy-needed-for-brome-grass-control

Barley grass is a problem for a number of reasons:

- Barley grasses act as an alternate host for a number of cereal diseases.
- Seeds of barley grasses cause stock health problems.
- Post-emergent herbicide control is limited in cereals.
- Barley grasses are readily dispersed.
- Populations of barley grasses can develop resistance to herbicides. [10]

6.1.6 Emerging flaxleaf fleabane threat

Flaxleaf fleabane (Photo 5) is a major weed in dryland crops in southern Queensland and northern New South Wales, and is emerging as a problem weed across the entire cereal-cropping belt of southern Australia.

Photo 5: *Flaxleaf fleabane.*

Source: GRDC

Previously, fleabane was found mainly on roadsides, particularly where council use of glyphosate created bare ground on which the weed could flourish without competition. However, the weed is highly mobile and soon found its way into adjacent cropping systems.

With the move to minimum tillage and the increasing use of glyphosate, the scene was set for an expansion of this troublesome weed. Wet summers in southern grain regions over the past two years have aided the weed's spread.

Fallow weed control costs have increased markedly because of fleabane, with some zero-till growers having to reintroduce cultivation as a last-resort control tactic. Disturbingly, populations of fleabane have recently been confirmed as resistant to eight times the normal rate of glyphosate, earning fleabane the title of Australia's first glyphosate-resistant broadleaf weed.

Control strategy

While fleabane presents a serious and costly weed challenge, GRDC-funded research has shown that a strategic approach using integrated weed management (IWM) can significantly reduce the weed's impact on crop production.

10 GRDC. Integrated weed management hub: Barley grass, https://grdc.com.au/Resources/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping/Barley-grass

The key to getting on top of fleabane is to attack all parts of the weed's life cycle to keep the seedbank low. Adopting an IWM strategy, which includes chemical and non-chemical tactics, will result in substantially fewer fleabane problems and resistant populations in subsequent seasons.

With the capacity to produce two or three generations each year and 110,000 seeds per plant, controlling fleabane before it sets seed is critical.

In southern and western Australia, fleabane often germinates under crops during spring or at harvest. Following harvest, a lack of crop competition combined with summer rain can cause rapid weed growth. By the time there is a window for control, the fleabane plants are often mature, with a large root system, a reduced leaf area and a high tolerance to most herbicides.

Research across Australia indicates that hitting the weed with herbicide while it is young and actively growing is the best approach. Conversely, delaying herbicide application until the weed is mature and water-stressed can result in poor control.

The "double-knock' approach, with glyphosate followed by paraquat, has proved a critical component of a fleabane IWM program.

This approach, coupled with the use of competitive crops and pastures and strategic cultivations to bury "blowouts" of seed production, can reduce the weed's seedbank to manageable levels within a few seasons. It is also important to target fencelines and roadsides. [11]

MORE INFORMATION

Managing Flaxleaf fleabane factsheet.

Flaxleaf fleabane – a weed best management guide.

VIDEOS

WATCH: GCTV4: Flaxleaf fleabane.

6.1.7 Feathertop Rhodes Grass management

A shift to minimum tillage and increasing glyphosate use across southern Queensland and northern New South Wales has created the perfect environment for feathertop rhodes grass (FTR) to flourish (Photo 6). A problem weed in Central Queensland for many years, FTR has only become an issue further south recently. Previously it was only a roadside weed in these areas. GRDC-funded research has shown that no single management strategy will effectively control FTR. A variety of tactics across rotations is required to keep on top of the troublesome weed.

Photo 6: *Feathertop rhodes grass.*

Source: GRDC

As with all problem weeds, the aim is to deplete the seedbank, control seedlings and small plants, stop seed set and prevent new seeds entering from outside the system.

Research has been determining the most effective herbicide and cultural controls for managing FTR in fallow and cropping systems. A newly funded GRDC project

11 M Widderick (2013) Fleabane now a national challenge, GRDC Ground cover supplement.

"Improving IWM practices in the Northern Region" is investigating FTR ecology and other control options.

Fallow control

Annual grasses can rapidly develop resistance to "fop" chemistry. To reduce the rate at which this occurs in FTR, the PER12941 permit limits Verdict® 520 use to one application per season in fallow, and this must be followed by a double knock application of at least 1.6 litres per hectare of a 250 g/L paraquat product.

Research has found that once FTR is past early tillering, a Group M (glycine) herbicide used alone becomes ineffective, but if a Group L bipyridyl herbicide is applied sequentially FTR control approaches 100%. This double-knock tactic has proved the most consistent and effective approach across a range of growth stages and plant stress conditions. The same research shows that adding residuals (particularly Group B) to the second knock enhances the effect of the Group L herbicide. The interval between knocks is important to overall efficacy. For many weeds, the interval required is short (three to four days), but FTR research by the GRDC-supported Northern Grower Alliance found that a minimum of seven days is necessary when using a Group M as the first knock. This is probably due to an antagonism that occurs inside the plant and is specific to FTR.

The double-knock tactic works best when applied to small, actively growing weeds, and rates for both knocks are robust. Applying the second knock as a spot spray, or using weed-detection technology (if available), can cut herbicide costs. Spot tillage is also an option and, in some instances, the second knock can be a 'spot' tillage operation instead of herbicide.

In-crop control

In-crop control of FTR will be limited by the herbicides that can be safely used within specific crops. For post-emergence control, shielded sprayers might be required (Group L and M herbicides in most crops, and Group A herbicides in some grass and cereal crops). Research has shown that several of the grass-selective Group A herbicides control FTR well, however, butroxydim and clethodim are the only Group A herbicides registered for in-crop FTR control.

Research is examining other Group A herbicides, which may perform better. Grass-selective knockdown herbicides are widely used in broadleaf crops such as mungbeans, chickpeas, cotton and sunflowers. Growing these crops in the rotation will help manage FTR. In addition, certain Group A herbicides used in wheat and barley provide effective post-emergence control of FTR, so winter cereals are a good option in an FTR integrated weed management plan.

Most weed control tactics rarely achieve 100% control, so monitoring for and controlling survivors is important. Controlling survivors as soon as possible by spot tillage, spot spraying (including weed sensor spray technology) or manual removal will avoid further seed set and minimise future problems. [12]

6.2 Using crop competition for weed control in durum

Durum wheat has typically been a poor performer in terms of competitiveness with weeds. This characteristic, as well as other issues, has turned many farmers away from durum cropping. There is considerable need to improve weed control in durum; an integrated approach to weed control will need to be adopted to maintain durum in rotations. [13]

Research conducted over the past three years by the Southern Australian Durum Growers Association has investigated the best management system for tackling weed issues in durum crops. A trial conducted at Hart, South Australia (SA), in 2014 compared the new durum variety DBA Aurora(D) to the wheat variety Mace

VIDEOS

WATCH: GCTV19: Feathertop Rhodes Grass. Important weed management recommendations.

WATCH: Ecology and management of feathertop Rhodes grass

12 M Widderick (2013) Feathertop heads south, GRDC Ground cover supplement.

13 GRDC (2015) Durum expansion in SA through improved agronomy – DGA00001. Grains Research and Development Corporation, March 2015, http://finalreports.grdc.com.au/DGA00001

to determine what management packages worked best and how the two crop types compared. The major finding was that both crops showed similar weed competitiveness. As detailed in Table 2, key findings included:

- In both crops, increasing the seeding rate reduced ryegrass head set.
- Both crops were similar in their ability to reduce ryegrass seed set.
- Mace had less yield loss than DBA Aurora(D when under high weed pressure.
- Varying seeding rates can change the amount of crop yield loss under high weed pressure.
- No significant difference in ryegrass control was found between normal and spreader seeder boots.

Competitive varieties are an important part of integrated weed management systems and should be considered when planning for weed control. Increasing seeding rates improves yield by out-competing weeds and reducing the amount of weeds that set seed. [14]

Table 2: *The effect of seed rate and normal and spreader seeding boots on grain yield (t/ha), and grass seed set (heads/m²), when sown to DBA-Aurora(D durum wheat and Mace(D wheat at Hart, SA, in 2014. Yield loss percentage is the difference between plots with high weed pressure compared to no weed pressure.*

Variety	Seeding boot	Seeding rate (kg/ha)	Yield loss %	Rye grass heads/m²	Yield t/ha
DBA Aurora(D	Normal boots	100	9.26	138	2.29
DBA Aurora(D	Normal boots	200	12.16	90	2.44
DBA Aurora(D	Normal boots	300	8.17	29	2.95
Mace(D	Normal boots	100	9.61	100	3.02
Mace(D	Normal boots	200	11.52	79	3.52
Mace(D	Normal boots	300	3.94	52	3.75
DBA Aurora(D	Spreader boots	100	18.34	104	2.41
DBA Aurora(D	Spreader boots	200	10.80	67	2.75
DBA Aurora(D	Spreader boots	300	9.16	54	3.02
Mace(D	Spreader boots	100	8.26	138	3.19
Mace(D	Spreader boots	200	8.72	90	3.75
Mace(D	Spreader boots	300	7.27	29	3.83
	LSD		2.59	30	0.27

Source: Grains Research and Development Corporation

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

6.2.1 Herbicides explained

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.

Residual and non-residual

Residual herbicides remain active in the soil for an extended period (months) and can act on successive weed germinations. Residual herbicides must be absorbed through the roots or shoots, or both. Examples of residual herbicides include 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/irrigation, temperature and the herbicide's characteristics. Persistence of herbicides will affect the enterprise's sequence (a rotation of crops, e.g. wheat > barley > chickpeas > canola > wheat). Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and they are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

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, while pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. [15]

Herbicides have been classified into a number of "groups". The group refers to the way a chemical works—their different chemical make-up and mode of action (Table 3). [16]

Table 3: *Herbicide groups and examples of chemical products in each group.*

Group A	Hoegrass®, Nugrass®, Digrass®, Verdict®, Targa®, Fusilade®, Puma S®, Tristar®, Correct®, Sertin® Grasp®, Select®, Achieve®, Gallant®, Topik®
Group B	Glean®, Chlorsulfuron, Siege®, Tackle®, Ally®, Associate®, Logran®, Nugran®, Amber Post® Londax®, Spinnaker®, Broadstrike®, Eclipse®, Renovate®
Group C	Simazine, Atrazine, Bladex®, Igran®, Metribuzin, Diuron, Linuron, Tribunil®, Bromoxynil, Jaguar®, Tough®
Group D	Trifluralin, Stomp®, Yield®, Surflan®
Group E	Avadex®, BW, EPTC, Chlorpropham
Group F	Brodal®, Tigrex®, Jaguar®
Group H	Saturn®
Group I	2,4-D, MCPA, 2,4-DB, Dicamba, Tordon®, Lontrel®, Starane®, Garlon®, Baton®, Butress®, Trifolamine®
Group J/K	Boxer Gold®
Group K	Dual®, Kerb®, Mataven®
Group L	Reglone®, Gramoxone®, Nuquat®, Spraytop®, Sprayseed®
Group M	Glyphosate, Glyphosate CT®, Sprayseed®, Roundup CT®, Touchdown®, Pacer®, Weedmaster®

List of commonly used products only.
List of products does not necessarily imply state registration.

15 GRDC Integrated weed management, Section 4: Tactics for managing weed populations, http://www.grdc.com.au/~/media/A4C48127FF8A4B0CA7DFD67547A5B716.pdf

16 Agriculture Victoria. Monitoring Tools, http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

Check that product is registered in your state before use. Groups G and J not included.

Source: DPI NSW

VIDEOS

WATCH: GCTV17: Herbicide partnership.

WATCH: GRDC – Managing herbicide-resistant ryegrass with integrated weed management.

6.3 Pre-emergent herbicides

Good weed control is essential to make full use of stored summer rainfall, minimise yield losses and prevent weed seed contamination at harvest. Effective weed control can be achieved by growing competitive durum crops, controlling weeds in preceding crops and fallow, rotating crops and the judicious use of herbicides. There are limited safe and effective herbicide options in durum to control annual ryegrass and the older varieties have been typically shown to be less competitive than bread wheat and barley. [17]

With the continued evolution of herbicide resistance, growers are being forced to implement a range of different weed control tactics. A tactic that has rapidly increased in recent seasons is the use of pre-emergent herbicides, especially in the summer crop and fallow. To predict field performance of these herbicides, an understanding is needed of their chemical properties and how they interact with the environment. When devising a weed control strategy, consider the use of pre-emergent herbicides as an additional tactic available to help drive weed numbers down. Used alone they usually will not achieve the objective of reducing weed seedbank numbers, but when used amongst a suite of tactics they can be particularly effective.

Pre-emergent herbicides control weeds between radicle (root shoot) emergence from the seed and seedling emergence through the soil. Some pre-emergent herbicides may also provide post-emergent control.

Key points for using pre-emergent herbicides

- Knowing which weeds are in the paddock and where the weed seeds are located (shallow or deep) is important in selecting a herbicide to be applied.
- Be aware of whether a herbicide is subject to volatilisation or photo-degradation in order to determine an incorporation strategy that minimises losses to the environment.
- Solubility influences how much rain is required for herbicide incorporation, how easily a herbicide will be taken up by a germinating weed and crop and whether a herbicide will be likely to move down the soil profile—potentially causing crop injury or loss to leaching.
- Sandy or low organic matter soils will have less binding and allow greater herbicide availability for crop and weed uptake.
- Herbicides that bind tightly to soil and organic matter generally require higher application rates, stay close to where they are applied (unless the soil moves) and persist for longer.
- Soil pH affects how long some herbicides persist for and how available they are for plant uptake and soil binding.
- The persistence of a herbicide and the way in which it breaks down will dictate the length of residual control and plant-back constraints to sensitive crops.
- Rainfall after application is important for incorporation and availability to the weeds and crop for a number of pre-emergent herbicides. Rainfall and temperature also affect degradation.
- Application rate will affect length of residual, and possibly crop selectivity.
- If using your sowing system for mechanical incorporation of pre-emergent herbicides, understand how speed, row spacing and row configuration impacts soil throw and subsequent chemical incorporation. [18]

17 GRDC (2015) Durum expansion in SA through improved agronomy – DGA00001. Grains Research and Development Corporation, March 2015, http://finalreports.grdc.com.au/DGA00001

18 GRDC (2015) Pre-emergent herbicides fact sheet. Grains Research and Development Corporation, December 2015, https://grdc.com.au/GRDC-FS-PreEmergentHerbicide

Photo 7: *Annual ryegrass is widespread across Australia and prone to herbicide resistance. It accounts for the highest overall cost to Australian grain production but several other weeds are becoming increasingly costly to growers.*

Source: Weedsmart

Choosing herbicides for weed control in wheat will depend on the specific weed species present in the paddock and the variety 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.

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 the amount of organic matter and crop residue on the surface); the solubility of the herbicide; and its ability to be bound by the soil. [19]

Benefits of pre-emergent herbicides

The residual activity of a pre-emergent herbicide controls the first few flushes of germinating weeds (cohorts) when the crop 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. [20]

Benefits and issues

- The residual activity of pre-emergent herbicides controls the first few flushes of germinating weeds while the crop or pasture is too small to compete.
- Good planning is needed to use pre-emergent herbicides as an effective tactic. It is necessary to consider weed species and density, crop or pasture type, soil condition and rotation of crop or pasture species.
- Soil activity and environmental conditions at the time of application play an important role in the availability, activity and persistence of pre-emergent herbicides.

19 GRDC (2014), Understanding pre-emergent cereal herbicides https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides

20 GRDC (2014), Understanding pre-emergent cereal herbicides https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides

- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [21]

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; and
- its ability to be bound by the soil.

Understanding pre-emergent herbicides

With the increasing incidence of resistance to post-emergent herbicides across Australia, pre-emergent herbicides are becoming more important for weed control. Pre-emergent herbicides typically have more variables that can affect efficacy than post-emergent herbicides. Post-emergent herbicides are applied when weeds are present and usually the main considerations relate to application coverage, weed size and environmental conditions that impact on performance and crop growth stage. Pre-emergent herbicides are applied before the weeds germinate and a number of other considerations come into play. The various pre-emergent herbicides behave differently in the soil and may behave differently in different soil types. Therefore, it is essential to understand the behaviour of the herbicide, the soil type and the farming system in order to use pre-emergent herbicides in the most effective way.

Pre-emergent herbicides have to be absorbed by the germinating seedling from the soil. To do so, these herbicides need to have some solubility in water and be in a position in the soil to be absorbed by the roots or emerging shoot. The dinitroaniline herbicides, such as trifluralin, are an exception in that they are absorbed by the seedlings as a gas. These herbicides still require water in order to be released from the soil as a gas. Therefore, weed control with pre-emergent herbicides will always be lower under dry conditions.

Behaviour of pre-emergent herbicides in the soil

Behaviour of pre-emergent herbicides in the soil is driven by three key factors:

- solubility of the herbicide,
- how tightly the herbicide is bound to soil components, and
- the rate of breakdown of the herbicide in the soil.

Characteristics of some common pre-emergent herbicides are given in Table 4.

The water solubility of herbicides ranges from very low values for trifluralin to very high values for chlorsulfuron. Water solubility influences how far the herbicide will move in the soil profile in response to rainfall events. Herbicides with high solubility are at greater risk of being moved into the crop seed row by rainfall and potentially causing crop damage. If the herbicides move too far through the soil profile they risk moving out of the weed root zone and failing to control the weed species at all. Herbicides with very low water solubility are unlikely to move far from where they are applied.

21 DAFWA (2016) Herbicides, https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2

Table 4: *Water solubility, binding characteristics to soil organic matter and degradation half-life for some common pre-emergent herbicides.*

Herbicide	Water solubility		Koc		Degradation half-life (days)
	mg L^{-1} (at 20 C and neutral pH)	Rating	mL g^{-1} (in typical neutral soils)	Rating	
Trifluralin	0.22	Very low	15,800	Very high	181
Pendimethalin	0.33	Very low	17,800	Very high	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	3,000	High	82
Prosulfocarb	13	Low	2,000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	75.5
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23
Chlorsulfuron	12,500	Very High	40	Low	160

Source: C. Preston, University of Adelaide

The important factors in getting pre-emergent herbicides 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; and its ability to be bound by the soil. Managing all these factors is complex, but some rules of thumb are:

1. Soils with low organic matter are particularly prone to crop damage from pre-emergent herbicides (especially sandy soils) and rates should be reduced where necessary to lower the risk of crop damage.
2. The more water-soluble herbicides will move more readily through the soil profile and are better suited to post sowing pre-emergent applications than the less water-soluble herbicides. They are also more likely to produce crop damage after heavy rain.
3. Pre-emergent herbicides need to be at sufficient concentration at or below the weed seed (except for triallate which needs to be above the weed seed) to provide effective control. Keeping weed seeds on the soil surface will improve control by pre-emergent herbicides.
4. High crop residue loads on the soil surface are not conducive to pre-emergent herbicides working well as they keep the herbicide from contact with the seed. More water-soluble herbicides cope better with crop residue, but the solution is to manage crop residue so that at least 50% of the soil surface is exposed at the time of application.
5. If the soil is dry on the surface but moist underneath, there may be sufficient moisture to germinate the weed seeds, but not enough to activate the herbicide. Poor weed control is likely under these circumstances. The more water-soluble herbicides are less adversely affected under these conditions.
6. Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular care needs to be taken with disc seeding equipment in choice of product and maintaining an adequate seeding depth. [22]

22 C Preston (2014) Understanding pre emergent cereal herbicides, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides

MORE INFORMATION

Understanding pre emergent cereal herbicides.

Using pre-emergent herbicides in conservation farming systems.

Gearing up to use pre-emergent herbicides.

GRDC Pre-emergent herbicides Factsheet.

How pre-emergent herbicides work.

VIDEOS

WATCH: GRDC Manual on pre-emergent herbicides – Incorporation by sowing

Top tips for using pre-emergent herbicides:

- Only use pre-emergent herbicides as part of an integrated weed control plan including both chemical and non-chemical weed control practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header.
- Minimise soil disturbance allowing weed seeds to remain on the soil surface.
- Leave stubble standing rather than laying it over.
- Knife points and press wheels allow greatest crop safety. Avoid harrows.
- If using a disc seeder, understand the mechanics of your machine and the limitations it may carry compared to a knife point and press wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter row whilst maintaining a seed furrow free from herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the seed.
- Ensure even seed placement, typically 3–5 cm of loose soil on top of seed in cereals for best crop safety.
- Use incorporation by sowing (IBS) practices rather than post sowing, pre-emergence (PSPE) for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [23]

6.4 Post-plant pre-emergent herbicides

When selecting a herbicide it is important to know the weeds present, the crop growth stage, the recommended growth stage for herbicide application, and the herbicide history of the paddock. Weeds should be sprayed while they are small and actively growing. It is important to rotate between herbicide groups to prevent weeds developing herbicide resistance. Herbicide labels should be read carefully before use as their use patterns vary. Research has found that durum cultivars differ in their tolerance to herbicides registered for use in durum wheats. [24]

6.5 In-crop herbicides: knock downs and residuals

These products control weeds that have emerged since crop or pasture establishment.

Benefits:

- Post-emergent herbicides give high levels of target weed control with the additional benefit of improved crop or pasture yield.
- Observations made just prior to application allow fine-tuning of herbicide selection to match weeds present in the paddock.
- Timing of application can be flexible to suit weed size, crop growth stage and environmental conditions.
- Some post-emergent herbicides have pre-emergent activity on subsequent weed germinations.

Issues:

- Use careful consideration when selecting the best post-emergent herbicide to use in any one situation.
- Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.
- Crop competition is important for effective weed control when using selective post-emergent herbicides.

23 B Haskins. Using pre-emergent herbicides in conservation farming systems. DPI NSW, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

24 DAFQ (2012) Durum wheat in Queensland. Department of Agriculture and Fisheries Queensland, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

- The technique used for application must be suited for the situation in order to optimize control.
- Always use the correct adjuvant to ensure effective weed control.
- Choose the most suitable formulation of herbicide for each situation.
- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors. [25]

Key points for using in-crop herbicides:

- Knowledge of a product's ability to be translocated within the weed and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.
- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.
- Robust rates of products and appropriate water rates are often more important for achieving control than the nozzle type, but correct nozzle type can widen the spray window, improve deposition and reduce drift risk.
- Travel speed and boom height can affect control and drift potential.
- Application of herbicides in appropriate conditions for spraying is always important.
- Knowledge of potential herbicide resistance of targeted weeds. [26]

Effective post-emergent herbicide application is dependent upon adequate contact with above-ground plant shoots and leaves. Therefore, it is important that spray pressure and volume be adjusted for adequate plant coverage. Also, it is very important that the proper nozzles be used. Read the herbicide label for details.

For post-emergence herbicides, the chemical and physical relationships between the leaf surface and the herbicide often determine the rate and amount of uptake. Factors such as plant size and age, water stress, air temperature, relative humidity and herbicide additives can influence the rate and amount of herbicide uptake. Additives such as crop oil concentrates, surfactants or liquid fertiliser solutions can increase herbicide uptake by a plant. Application of herbicides under hot and dry conditions, or to older and larger weeds or weeds under water stress can decrease the amount of herbicide uptake. Differences in the rate and amount of herbicide uptake influence the potential for crop injury and weed control and often explain the year-to-year variation in the effectiveness of the herbicide.

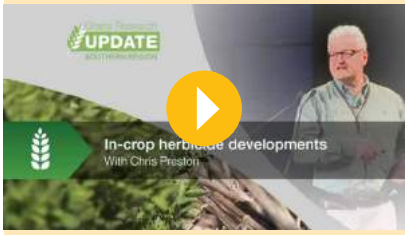
Also, the faster a herbicide is absorbed by a plant, the less likely that rain will wash the herbicide off the plants. Like soil-applied herbicides, post-emergent herbicides differ in their ability to move within a plant. For adequate weed control, non-mobile post-emergent herbicides must thoroughly cover the plant. Other herbicides are mobile within the plant and can move from the site of application to their site of herbicidal activity. In general, injury symptoms will be most prominent at the sites at which the mobile herbicides concentrate. [27]

How to get the most out of post-emergent herbicides:

- Consider application timing—the younger the weeds the better the weed kill. 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 were historically in the paddock and the resistance status of the paddock (if unsure, send plants away to 'Plant science consulting's Weed Resistance Quick test'.

VIDEOS

WATCH: GRDC Grains Research Updates 2015 – In-crop herbicide developments.



WATCH: GRDC Grains Research Updates 2015 – New technology for improved herbicide use efficiency

25 DAFWA (2016) Herbicides, https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2

26 GRDC (2014) In-crop herbicide use. Grains Research and Development Corporation, July 2014, http://grdc.com.au/GRDC-FS-InCropHerbicideUse

27 JL Gunsolus, WS Curran (1999) Herbicide mode of action and injury symptoms. University of Minnesota Extension Service – North Central Regional Extension Publication No. 377, http://www.cof.orst.edu/cof/fs/kpuettmann/FS%20533/Vegetation%20Management/Herbicide%20Mode%20of%20Action%20and%20Injury%20Symptoms.htm

MORE INFORMATION

GRDC In-crop herbicide use Fact sheet

- Do not spray a crop stressed by waterlogging, frost, high or low temperatures or, drought. 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 correct adjuvant.

6.6 Conditions for spraying

The problem

When applying herbicides, the aim is to maximise the amount reaching the target and to minimise the amount reaching off-target areas. This results in:

- improved herbicide effectiveness
- reduced damage and/or contamination of off target crops and areas

In areas where a range of agricultural enterprises coexists, conflicts can arise, particularly from the use of herbicides. All herbicides are capable of drift.

When spraying a herbicide, you have a moral and legal responsibility to prevent it from drifting and contaminating or damaging neighbours' crops and sensitive areas.

All grass herbicides labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions (Photo 8). Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, likely resulting in incomplete kill or only suppression of weeds:

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

Photo 8: *Boom spray on crop.*

Source: DAFWA

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

6.6.1 Minimising spray drift

Before spraying

- Always check for susceptible crops in the area, for example broadleaf crops such as grape vines, cotton, vegetables and pulses if you are using a broadleaf herbicide.
- Check sensitive areas such as houses, schools, waterways and riverbanks.
- Notify neighbours of your spraying intentions.

Under the Records Regulation of the Pesticides Act 1999, when spraying you must record the weather and relevant spray details.

During spraying

- Always monitor weather conditions carefully and understand their effect on "drift hazard".
- Do not spray if conditions are not suitable, and stop spraying if conditions change and become unsuitable.
- Record weather conditions (especially temperature and relative humidity), wind speed and direction, herbicide and water rates, and operating details for each paddock.
- Supervise all spraying, even when a contractor is employed. Provide a map marking the areas to be sprayed, buffers to be observed and sensitive crops and areas.
- Spray when temperatures are less than 28°C.
- Maintain a downwind buffer. This may be incrop, for example keeping a boom's width from the downwind edge of the field.
- Minimise spray release height.
- Use the largest droplets that will give adequate spray coverage.
- Always use the least-volatile formulation of herbicide available.

- If there are sensitive crops in the area, use the herbicide that will cause no off-target impacts.

Delta T

Delta T values indicate evaporative potential. High values can reduce droplet survival in the air and at the target. Airborne droplets will rapidly decrease in size when the delta T value of the air exceeds 8 to 10 (Figure 2). When using a coarse spray quality or larger, also check the Delta T value at the target and avoid values above 10 to 12. Low Delta T values (below 2) encourage droplet survival, which can increase the risk of spray drift. Using the coarsest droplets that will provide efficacy will reduce the airborne fraction and increase droplet survival times.

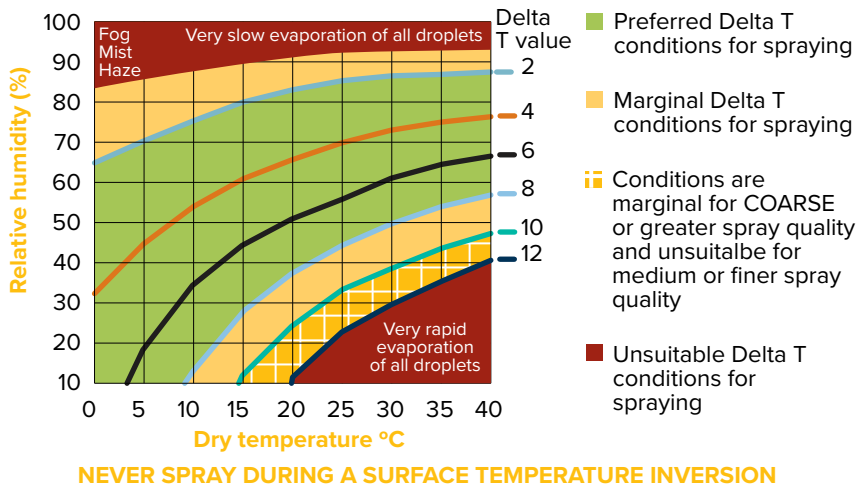


Figure 2: *The relationship of Delta T to relative humidity and temperature. A Common spray guideline is to spray when Delta T is between 2 and 8; with caution below 2 or above 10.*

Source: GRDC, Adapted by Graeme Tepper (2012), originally sourced from Nufarm's Spraywise Decisions Chart (2012).

MORE INFORMATION

Practical tips for spraying Fact sheet.

6.6.2 Types of Drift

Sprayed herbicides can drift as droplets, as vapours or as particles.

Droplet drift is the easiest to control because under good spraying conditions, droplets are carried down by air turbulence and gravity, to collect on plant or soil surfaces. Droplet drift is the most common cause of off-target damage caused by herbicide application. For example, spraying fallows with glyphosate under the wrong conditions often leads to severe damage to establishing crops.

Particle drift occurs when water and other herbicide carriers evaporate quickly from the droplet leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. Instances of this form of drift have damaged susceptible crops up to 30 km from the source.

Vapour drift is confined to volatile herbicides such as 2,4-D ester. Vapours may arise directly from the spray or evaporation of herbicide from sprayed surfaces. Use of 2,4-D ester in summer can lead to vapour drift damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans and grapes. This may occur hours after the herbicide has been applied.

In 2006 the federal regulators of pesticide use, the APVMA, restricted the use of highly volatile forms of 2,4-D ester. The changes are now seen with the substitution of lower volatile forms of 2,4-D and MCPA. Products with lower "risk" ester formulations

are commonly labelled with LVE—short for low volatile ester. These formulations of esters have a much lower tendency to volatilise, but caution still remains, as they are still prone to droplet drift.

Vapours and minute particles float in the airstream and are poorly collected on catching surfaces. They may be carried for many kilometres in thermal updraughts before being deposited.

Sensitive crops may be up to 10,000 times more sensitive than the crop being sprayed. Even small quantities of drifting herbicide can cause severe damage to highly sensitive plants.

6.6.3 Factors affecting the risk of spray drift

Any herbicide can drift. The drift hazard, or off-target potential, of a herbicide in a particular situation depends on the following factors:

- Volatility of the formulation applied. Volatility refers to the likelihood that the herbicide will evaporate and become a gas. Esters volatilise (evaporate) whereas amines do not.
- Proximity of crops susceptible to the particular herbicide being applied, and their growth stage. For example cotton is most sensitive to Group I herbicides in the seedling stage.
- Method of application and equipment used. Aerial application releases spray at 3 m above the target and uses relatively low application volumes, while ground rigs have lower release heights and generally higher application volumes, and a range of nozzle types. Misters produce large numbers of very fine droplets that use wind to carry them to their target.
- Size of the area treated—the greater the area treated the longer it takes to apply the herbicide. If local meteorological conditions change, particularly in the case of 2,4-D ester, then more herbicide is able to volatilise.
- Amount of active ingredient (herbicide) applied—the more herbicide applied per hectare the greater the amount available to drift or volatilise.
- Efficiency of droplet capture—bare soil does not have anything to catch drifting droplets, unlike crops, erect pasture species and standing stubbles.
- Weather conditions during and shortly after application.

Changing weather conditions can increase the risk of spray drift.

Volatility

Many ester formulations are highly volatile when compared with the non-volatile amine, sodium salt and acid formulations.

Table 5 is a guide to the more common herbicide active ingredients that are marketed with more than one formulation.

Table 5: *Relative herbicide volatility.*

Form of active	Full name	Product example
NON-VOLATILE		
Amine salts		
MCPA dma	dimethyl amine salt	MCPA 500
2,4-D dma	dimethyl amine salt	2,4-D Amine 500
2,4-D dea	diethanolamine salt	2,4-D Amine 500 Low Odour®
2,4-D ipa	isopropylamine salt	Surpass® 300
2,4-D tipa	triisopropanolamine	Tordon® 75-D
2,4-DB dma	dimethyl amine salt	Buttress®
dicamba dma	dimethyl amine salt	Banvel® 200
triclopyr tea	triethylamine salt	Tordon® Timber Control
picloram tipa	triisopropanolamine	Tordon® 75-D
clopyralid dma	dimethylamine	Lontrel® Advanced
clopyralid tipa	triisopropanolamine	Archer®
aminopyralid K salt	potassium salt	Stinger®
aminopyralid tipa	triisopropanolamine	Hotshot®
Other salts		
MCPA Na salt	sodium salt	MCPA 250
MCPA Na/K salt	sodium & potassium salt	MCPA 250
2,4-DB Na/K salt	sodium & potassium salt	Buticide®
dicamba Na salt	sodium salt	Cadence®
SOME VOLATILITY		
Ester		
MCPA ehe	ethylhexyl ester	LVE MCPA
MCPA ioe	isooctyl ester	LVE MCPA
triclopyr butoxyl	butoxyethyl ester	Garlon® 600
picloram ioe	isooctyl ester	Access®
2,4-D ehe	ethylhexyl ester	2,4-D LVE 680
fluroxypyr M ester	meptyl ester	Starane® Advanced

Source: Mark Scott, former Agricultural Chemicals Officer, NSW Agriculture

6.6.4 Minimising drift

A significant part of minimising spray drift is the selection of equipment to reduce the number of small droplets produced. However, this in turn may affect coverage of the target, and therefore the possible effectiveness of the pesticide application.

This aspect of spraying needs to be carefully considered when planning to spray.

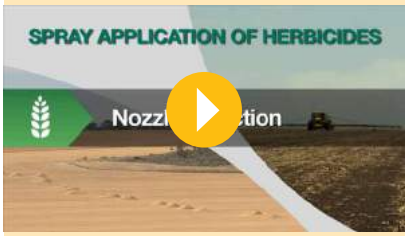
As the number of smaller droplets decreases, so does the coverage of the spray.

A good example of this is the use of air-induction nozzles that produce large droplets that splatter. These nozzles produce a droplet pattern and number that are unsuitable for targets such as seedling grasses that present a small vertical target.

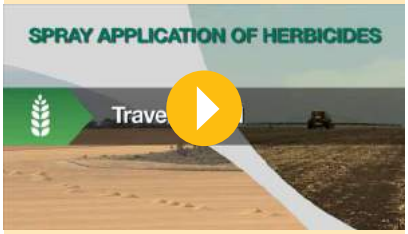
In 2010, the APVMA announced new measures to ensure the number of spray drift incidents is minimized (Table 6). The changes are restrictions on the droplet size spectrum an applicator could use, wind speed suitable for spraying and the downwind buffer zone between spraying and a sensitive target. These changes

VIDEOS

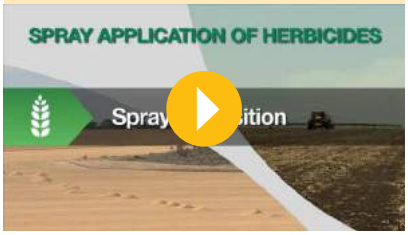
WATCH: Nozzle Selection.



WATCH: Travel Speed.



WATCH: Spray deposition.



should be evident on current herbicide labels. Hand held spraying application is exempt to these regulations.

Table 6: *Nozzle selection guide for ground application.*

Distance downwind to susceptible crop	< 1 km	1 to 30 km >
Risk	High	Medium
Preferred droplet size (British Crop Protection Council) (to minimise risk)	coarse to very coarse	medium to coarse
Volume median diameter (microns)	310	210
Pressure (bars)	2.5	2.5
Flat fan nozzle size #	11,008	11,004
Recommended nozzles (examples only)	Raindrop Whirljet® Air induction Yamaho Turbodrop® Hardi Injet® AI Teejet® LurmarkDrift-beta®	Drift reduction DG TeeJet® Turbo TeeJet® Hardi® ISO LD 110 Lurmark® Lo-Drift
CAUTION	Can lead to poor coverage and control of grass weeds. Require higher spray volumes.	Suitable for grass control at recommended pressures. Some fine droplets.

Volume Median Diameter (VMD): 50% of the droplets are less than the stated size and 50% greater.
Refer to manufacturers' selection charts, as droplet size range will vary with recommended pressure. Always use the lowest pressure stated to minimise the small droplets. (Adapted from P. Hughes, DPI, Queensland.)

Source: DPI NSW

6.6.5 Spray release height

- Operate the boom at the minimum practical height. Drift hazard doubles as nozzle height doubles. If possible, angle nozzles forward 30° to allow lower boom height with double overlap. Lower heights, however, can lead to more striping, as the boom sways and dips below the optimum height.
- 110° nozzles produce a higher percentage of fine droplets than 80° nozzles, but they allow a lower boom height while maintaining the required double overlap.
- Operate within the pressure range recommended by the nozzle manufacturer. Production of driftable fine droplets increases as the operating pressure is increased.

6.6.6 Size of area treated

When large areas are treated, relatively large amounts of active herbicide are applied and the risk of off-target effects increases due to the length of time taken to apply the herbicide. Conditions such as temperature, humidity and wind direction may change during spraying.

Applying volatile formulations to large areas increases the chances of vapour drift damage to susceptible crops and pastures.

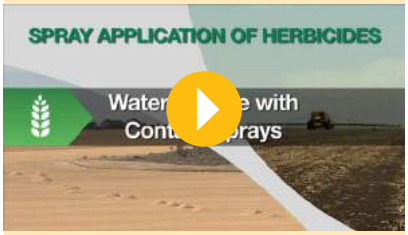
6.6.7 Capture surface

Targets vary in their ability to collect or capture spray droplets. Well grown, leafy crops are efficient collectors of droplets. Turbulent airflow normally carries spray droplets down into the crop within a very short distance.

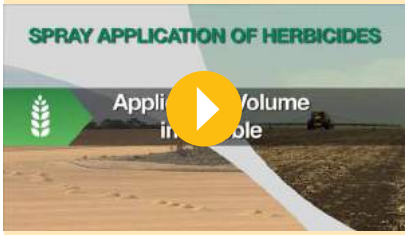
Fallow paddocks or seedling crops have poor catching surfaces. Drift hazard is far greater when applying herbicide in these situations or adjacent to these poor capture surfaces.

VIDEOS

WATCH: Water Volume with contact sprays.



WATCH: Application Volume in stubble.



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

The type of catching surface between the sprayed area and susceptible crops should always be considered in conjunction with the characteristics of the target area when assessing drift hazard.

6.6.8 Weather conditions to avoid

Midday turbulence

- Up-drafts during the heat of the day cause rapidly shifting wind directions. Spraying should be avoided during this time of day.

High temperatures

- Avoid spraying when temperatures exceed 28°C.

Humidity

- Avoid spraying under low relative humidity conditions, i.e. when the difference between wet and dry bulbs (Delta T, ΔT) exceeds 10°C.
- High humidity extends droplet life and can greatly increase the drift hazard under inversion conditions. This results from the increased life of droplets smaller than 100 microns.

Wind

- Avoid spraying under still conditions.
- Ideal safe wind speed is 3–10 km/h, a light breeze (leaves and twigs are in constant motion).
- 11–14 km/h (a moderate breeze) is suitable for spraying if using low drift nozzles or higher volume application, 80-120 L/ha (small branches move, dust is raised and loose paper is moving).

Inversions

The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity.

Do not spray under inversion conditions.

An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, usually less than 50 m thick. Air will not rise above this blanket; and smoke or fine spray droplets and particles of spray deposited within an inversion will float until the inversion breaks down.

Inversions usually occur on clear, calm mornings and nights. Windy or turbulent conditions prevent inversion formation. Blankets of fog, dust or smoke and the tendency for sounds and smells to carry long distances indicate inversion conditions.

Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion "blanket". [28]

6.7 Herbicide tolerance ratings, NVT

Durum wheats can be more sensitive to some herbicides that are commonly and safely used in bread wheat. Within many broadacre crop species, cultivars have been found to vary in sensitivity to commonly used herbicides and tank mixes, thereby Knowing a durum variety's herbicide tolerance rating would enable a grower to select the appropriate non damaging herbicide for that variety or alternatively select the appropriate variety to use with the herbicides wanting to be used thus avoiding an potential yield loss. resulting in potential grain yield loss and reduced farm profit.

28 A Storrie (2015) Reducing herbicide spray drift. DPI NSW, http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift

With funding from GRDC and state government agencies across Australia, a series of cultivar × herbicide tolerance trials are conducted annually. The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species. The intention is to provide data from at least two years of testing at the time of wide-scale commercial propagation of a new cultivar. The good news is that >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. [29]

Diagnosing Group B herbicide damage in cereals

Herbicide sensitivity trials suggest durum varieties are sensitive to various Group B herbicides. Growers are advised to read product labels and refer to the Weed control in winter crops guide for the latest information on variety tolerances. [30]

The three major Group B herbicides are sulfonlyureas (SUs), sulfonamides (SAs) and imidazolinones (Imis). SUs and SAs are systemic herbicides that are used for pre- and/or post-emergent grass and/or broadleaf weed control in cereals. Imis are toxic to most cereals and especially durums.

Paddock-scale symptoms:

- Normal crop emergence followed by paleness and stunting, particularly in alkaline (SUs only) and wetter areas (SAs persistence is increased in acidic soils).

Plant symptoms:

- Symptoms often appear five to eight days after germination or spray application.
- Emerging or young plants can be stunted with curled or spiky new leaves.
- Pale to yellow-red or purplish colouration of new leaves, that may show as inter-veinal chlorosis, streaks, mottles or blotches.
- Growth of lateral roots may be reduced.
- Imis may cause head damage.
- Tillering may be reduced, but SU- or SA-affected plants generally recover.
- Group B herbicide damaged plants are more susceptible to root disease, nematodes and trace element deficiencies. [31]

MORE INFORMATION

NVT Herbicide tolerance

6.8 Potential herbicide damage effect

Herbicides can cause damage to non-target plants in some circumstances. Injury can range from slight to serious and can result in economic damage. Herbicide chemistry and physical properties usually determine how herbicides interact with the biological and physical systems of the plant. Factors determining herbicide efficacy and crop safety are complex and include plant species, plant size, stage of growth, soil chemical and physical properties, soil moisture, temperature and relative humidity. Post-emergent herbicide uptake and efficacy can be affected by spray additives that enhance the performance of the herbicide but may also increase the risk of crop injury. Herbicides can injure foliage, shoots and flowers (Photo 9). Herbicide injury symptoms include general and interveinal chlorosis, mottled chlorosis, yellow spotting, purpling of the leaves, necrosis and stem dieback. [32]

29 GRDC (2017) South Australia Sowing Guide http://www.pir.sa.gov.au/__data/assets/pdf_file/0005/268862/SA_Sowing_Guide_2017.pdf

30 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. New South Wales Department of Primary Industries, ISSN-2206-3056, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

31 DAFWA (2015) Diagnosing group B herbicide damage in cereals. Department of Agriculture and Food Western Australia, June 2015, https://agric.wa.gov.au/n/1977

32 K Al-Khatib. Herbicide damage. University of California Division of Agriculture and Natural Resources, http://herbicidesymptoms.ipm.ucanr.edu/HerbicideDamage/

Photo 9: *Cereal plants showing herbicide damage caused by the presence of residues from the application of a triazine (such as atrazine) to the previous crop; symptoms are bleaching of the leaves followed by necrosis.*

Source: International Maize and Wheat Improvement Center

Good agronomic practice that promotes early crop health and vigour can assist in overcoming some low-level marginal damage. While any level of herbicide damage or setback to a young crop may potentially lead to a yield loss or change in phenology, and should thus be avoided, it is not uncommon for crops suffering from low-level herbicide damage in the early vegetative phases of growth to compensate and yield well despite their early setback. Growers relying on the crop's ability to compensate and grow out of early damage are, however, taking a significant risk. [33]

Timely and correct application of herbicides is essential. Seek local advice from advisers or agronomists and follow label directions. All chemical labels should be read carefully before the product is used, as the law requires that growers follow the label when using a product. New products and product formulations may have changed safety margins. Where herbicide residue may remain in the soil, avoid the use of herbicides from the same mode of action group in following crops. It is not uncommon to see a herbicide stress acting on top of an existing herbicide stress to make a potentially damaging residual situation worse.

6.8.1 Residual herbicides

Some herbicides can remain active in the soil for weeks, months or years. This can be an advantage, as 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.

A real difficulty for growers lies in identifying herbicide residues before they cause a problem. Currently, growers rely on information provided on the labels about 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. [34]

33 J Cameron, M Congreve (2016) Recropping issues with pre-emergent herbicides. Grains Research and Development Corporation, February 2016, https://grdc.com.au/RecroppingIssuesWithPreEmergentHerbicides

34 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Economic Development, Jobs, Transport and Resource, August 2013, 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

Which herbicides are residual?

The herbicides listed in Table 7 all have some residual activity or planting restrictions.

Table 7: *Active constituent by herbicide group (may not include all current herbicides).*

Herbicide Group	Active Constituent
Group B: Sulfonylureas	Chlorosulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)
Group B: Imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)
Group B: Triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)
Group C: Triazines	Atrazine, simazine
Group C: Triazinones	Metribuzin (Sencor®)
Group C: Ureas	Diuron
Group D: Dinitroanilines	Pendimethalin (Stomp®), trifluralin
Group H: Pyrazoles	Pyrasulfotole (Precept®)
Group H: Isoxazoles	Isoxaflutole (Balance®)
Group I: Phenoxycarboxylic acids	2,4-Ds
Group I: Benzoic acids	Dicamba
Group I: Pyridine carboxylic acids	Clopyralid (Lontrel®)
Group K: Chloroacetamides	Metolachlor
Group K: Isoxazoline	Pyroxasulfone (Sakura®)

How can I avoid damage from residual herbicides?

Select a herbicide appropriate for the weed population you have. Make sure you consider what the re-cropping limitations may do to future rotation options.

Users of chemicals are required by law to keep good records, including weather conditions, but particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock) (Photo 10). In the case of unexpected damage, good records can be invaluable.

Photo 10: *This trial plot is showing crop damage with pre-emergent herbicides due to poor separation of herbicide and crop seed.*

Photo: Dr Christopher Preston. Source: GRDC

MORE INFORMATION

Herbicide residues in Soil and Water.

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. [35]

6.8.2 Plant-back intervals

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

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods (e.g. sulfonylureas (chlorsulfuron)). This is shown in the Table 8 and 9 where known. Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the "Protection of crops etc." heading in the "General Instructions" section of the label.

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [36]

35 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Economic Development, Jobs, Transport and Resource, August 2013, 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

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

Table 8: *Residual persistence of common pre-emergent herbicides, and note residual persistence in broad-acre trials and paddock experiences.* [37]

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

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

Table 9: *Minimum re-cropping intervals and guidelines (NOTE: always read labels to confirm).*

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

Source: Pulse Australia

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the "Protection of crops etc." heading in the "General Instructions" section of the label. [38]

Conditions required for breakdown

Warm, moist soils are required to breakdown most herbicides through the processes of microbial activity. For the soil microbes to be most active they need good moisture and an optimum soil temperature range of 18°C to 30°C. Extreme temperatures above or below this range can adversely affect soil microbial activity and slow herbicide

38 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

MORE INFORMATION

Avoiding crop damage from residual herbicides

breakdown. Very dry soil also reduces breakdown. To make matters worse, where the soil profile is very dry it requires a lot of rain to maintain topsoil moisture for the microbes to be active for any length of time.

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

6.9 Herbicide resistance

Herbicide resistance facts:

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

Key messages

Resistance:

- Remains for many years, until all resistant weed seeds are gone from the soil seed bank.
- Evolves more rapidly in paddocks with frequent use of the same herbicide group, especially if no other control options are used.

Action points:

- Assess your level of risk with the online glyphosate resistance toolkit.
- Aim for maximum effectiveness in control tactics, because resistance is unlikely to develop in paddocks with low weed numbers.
- Do not rely on the same mode of action group.
- Monitor your weed control regularly.
- Stop the seed set of survivors. [39]

Herbicide resistance has become far more widespread, reducing the effectiveness of a wide range of herbicide modes-of-action (MOAs) (Photo 11). 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 modes of action that have not yet been released or indeed invented. Effective herbicides are

39 DAFF QLD (2015) Stopping herbicide resistance in Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

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

Photo 11: *2,4-D resistant radish, Wongan Hills.*

Photo: A Storrie in GRDC

MORE INFORMATION

GRDC IWM Hub - Herbicide resistance.

How does resistance start?

Resistance starts in a paddock in several ways. Some rare mutations can occur naturally in weeds already in the paddock, with the likelihood varying from 1 plant in 10,000 to 1 in a billion plants, depending on the weed and herbicide. A grower may also import weed seed with the herbicide-resistant gene in contaminated feed, seed or machinery.

Resistance may also be introduced by natural seed spread by wind and water or by pollen, which may blow short distances from a contaminated paddock.

6.9.1 General principles to avoid resistance

Herbicides have a limited life before resistance develops, if they are used repeatedly and exclusively as the sole means of weed control—particularly in zero and minimum tilled systems. Resistance can develop within four to eight years for Group A and B herbicides and after 15 years for Group L and M herbicides (see Table 10 and Figure 3). This can be avoided by:

- keeping weed numbers low
- changing herbicide groups
- using tillage
- rotating crops and agronomic practices

We have gained further insight into the impact and efficacy of integrated weed management strategy components through a computer-simulated model.

Table 10: *Rules of thumb for the number of years of herbicide application before resistance evolves.*

Herbicide group	Years to resistance
A	6–8
B	4–6
C	10–15
D	10–15
L	15+
M	15+

Source: Chris Preston, University of Adelaide, in DAFF

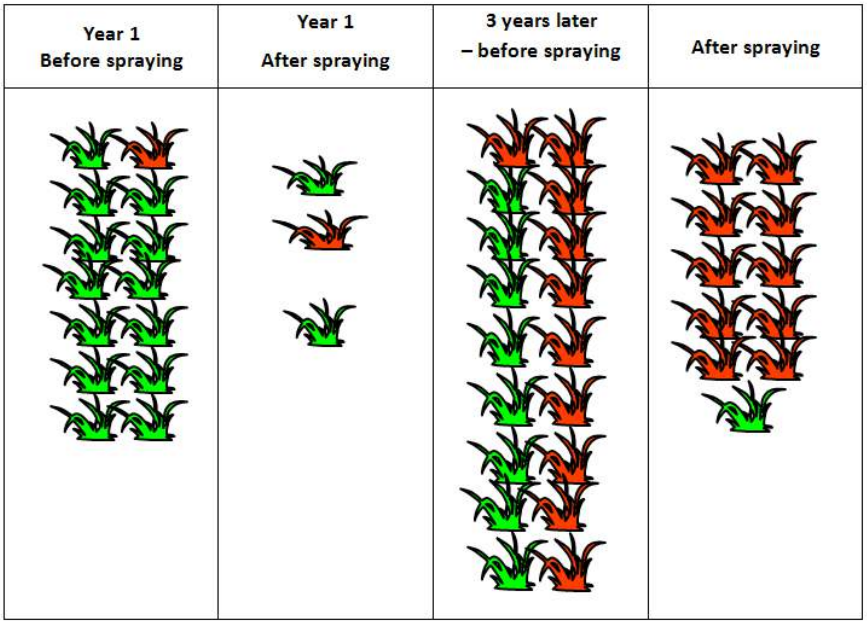


Figure 3: *How a weed population becomes resistant to herbicides.*

Source: GRDC

Strategies to prevent or minimise the risk of resistance developing are based on IWM principles as outlined below:

- Ensure survivors do not set seed and replenish the soil seed bank.
- Keep accurate paddock records of herbicide application and levels of control. Monitor weeds closely for low levels of resistance, especially in paddocks with a history of repeated use of the same herbicide group.
- Rotate between the different herbicide groups, and/or tank mix with an effective herbicide from another mode of action group. It is important to use effective "stand-alone" rates for both herbicides in the mix.
- Aim for maximum effectiveness to keep weed numbers low. The primary aim of weed control is to minimise their impact on productivity, and resistance is much less likely to develop in paddocks with fewer weeds than in heavily infested paddocks.
- Use a wide range of cultural weed control tools in your weed management plan. Sowing different crops and cultivars provides opportunities to use different weed management options on key weeds. Tillage is useful when it targets a major weed flush and minimises soil inversion, as buried weed seed generally persists longer than on the soil surface. Competitive crops will reduce seed production on weed survivors.

- Avoid introduction or spread of weeds by contaminated seed, grain, hay or machinery. Also, manage weeds in surrounding non-crop areas to minimise risk of seed and pollen moving into adjacent paddocks.

Specific guidelines for reducing the risk of glyphosate resistance are outlined in Table 11. Aim to include as many as possible risk-decreasing factors in your crop and weed management plans.

Table 11: *Balancing the risk for weeds developing glyphosate resistance, devised by the national Glyphosate Sustainability Working Group with minor modifications for the Queensland cropping region.*

Risk increasing	Risk decreasing
Continuous reliance on glyphosate pre-seeding	Double knock technique
Lack of tillage	Strategic use of alternative knockdown groups
Lack of effective in-crop weed control	Full-disturbance cultivation at sowing
Inter-row glyphosate use (unregistered)	Effective in-crop weed control
Frequent glyphosate-based chemical fallow	Use alternative herbicide groups or tillage for inter-row and fallow weed control
High weed numbers	Non-herbicide practices for weed seed kill
Pre-harvest desiccation with glyphosate	Farm hygiene to prevent resistance movement

(Source: DAFF

Glyphosate resistant weeds in Australia

Glyphosate resistance was first documented for annual ryegrass (*Lolium rigidum*) in 1996 in Victoria. Since then glyphosate resistance has been confirmed in 11 other weed species. Resistance is known in 8 grass species and 4 broadleaf species. There are 4 winter-growing weed species and 8 summer-growing weed species. The latter have been selected mainly in chemical fallows and on roadsides (Photo 12).

Photo 12: *Winter fallow showing an early glyphosate resistant sowthistle infestation.*

Photo: A Storrie. Source: GSWG

MORE INFORMATION

Australian glyphosate resistance register

VIDEOS

WATCH: Act now: Plan your weed management program.

WATCH: Chaff carts 101.

WATCH: Capture weed seeds at harvest: Harrington seed destructor.

WATCH: Strategic narrow windrow burning.

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

- Intensive use of glyphosate—every year or multiple times a year for 15 years or more.
- Heavy reliance on glyphosate for weed control.
- No other weed controls targeted to stop seed set.

Farming practices in chemical fallows are heavily dependent on glyphosate for weed control. Therefore, it is highly likely that unconfirmed populations of glyphosate resistant summer and winter weeds are present in this system.

Farming practices under the vines in vineyards across Australia are heavily dependent on glyphosate for weed control. Therefore, it is highly likely that unconfirmed populations of glyphosate resistant annual ryegrass are present in this system.

These unconfirmed glyphosate-resistant populations are not recorded on the register of glyphosate resistant populations in Australia. [40]

The online glyphosate resistance toolkit enables growers and advisors to assess their level of risk for developing glyphosate-resistant weeds on their farm.

6.9.2 10-point plan to weed out herbicide resistance

1. Act now to stop weed seed set.

Creating a plan of action is an important first step of integrated weed management. A little bit of planning goes a long way!

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

2. Capture weed seeds at harvest.

Destroying or capturing weed seeds at harvest is the number one strategy for combating herbicide resistance and driving down the weed seed bank.

- Tow a chaff cart behind the header.
- Check out the Harrington Seed Destructor. (Photo 13)
- Create and burn narrow windrows.
- Produce hay where suitable.
- Funnel seed onto tramlines in controlled traffic farming (CTF) systems.
- Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.

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.

40 C Preston. The Australian Glyphosate Sustainability Working Group, http://www.glyphosateresistance.org.au

VIDEOS

WATCH: The art of narrow windrow burning.

WATCH: Chaff funneling onto tramlines.

WATCH: Capture weed seeds at harvest: Bale Direct System.

WATCH: IWM: Weed seed destruction – Beer can height.

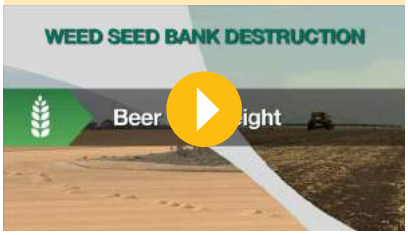


Photo 13: *Harrington weed seed destructor at work in the paddock.*

Source: GRDC

For information on harvest weed seed control and its application, see Section 12: Harvest.

3. Rotate crops and herbicide modes of action.

Crop rotation is great for farming systems! Make sure weed management is part of the decision when planning crop rotation.

Crop rotation offers many opportunities to use different weed control tactics, both herbicide and non-herbicide, against different weeds at different times.

Rotating crops also gives us a range of intervention opportunities. For example, we can crop top lupins/pulses, swath canola, and delay sowing some crops (like field peas).

Rotations that include both broadleaf crops, like pulses and oilseeds, and cereals allow the use of a wider range of tactics and chemistry.

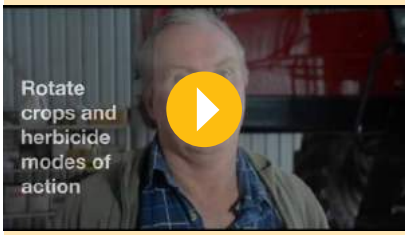
Growers also have the option of rotating to non-crop, e.g. pastures and fallows.

Within the rotation it is also important to not repeatedly use herbicides from the same mode of action (MOA) group. Some crops have less registered herbicide options than others so this needs to be considered too, along with the opportunities to use other tactics in place of one or more herbicide applications, such as harvest weed seed control.

Repeated use of herbicides with the same MOA is the single greatest risk factor for herbicide resistance evolution.

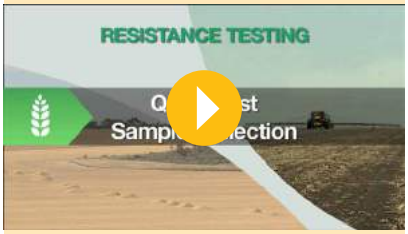
VIDEOS

WATCH: Crop rotation with Colin McAlpine.

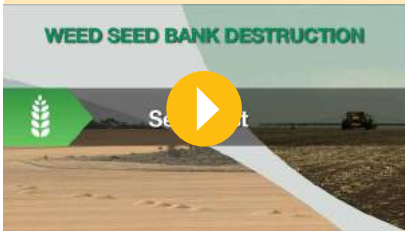


WATCH: Test for resistance to establish a clear picture of paddock-by-paddock farm status.

WATCH: IWM: Resistance Testing – Quick test sample collection.



WATCH: IWM: Seed test – What's involved.



4. Test for resistance to establish a clear picture of paddock-by-paddock farm 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.
- Collaborate with researchers by collecting weeds for surveys during the double-knock program.
- Visit WeedSmart for more information on herbicide-resistance survey results.

It is clearly too late to prevent resistance evolution for many of our common herbicides. However, a resistance test when something new is observed on-farm can be very useful in developing a plan to contain the problem, and in developing new strategies to prevent this resistance evolving further.

Perhaps the best use for herbicide resistance tests is to use them in a game changing situation such as the discovery of a rare resistance gene (e.g. glyphosate resistance) or to determine if a patch of surviving weeds are any worse than what the grower has observed before. This bad patch of weeds gives insight into the future resistance profile of the farm if it is not contained and resistance testing in these situations can be very useful in building preventative strategies.

5. Never cut the rate.

AHRI researcher Dr. Roberto Busi found that ryegrass receiving below the label recommended rate of Sakura® evolved resistance not only to Sakura® but also to Boxer Gold® and Avadex®.

Imagine developing these multiple resistant, monster weeds just because you cut the rate!

- Use best management practice in spray application.
- Consider selective weed sprayers such as WeedSeeker or WeedIt.

6. Don't automatically reach for glyphosate.

Glyphosate has long been regarded as the world's most important herbicide, so it's natural to reach for it at the first sign of weeds. But what if it didn't work anymore?

Resistance to this herbicide is shooting through the roof in some areas and this could be the first year we see it fail for growers all across Australia. Why? Too much reliance on one herbicide group gives the weeds opportunity to evolve resistance.

To preserve glyphosate as the wonder weed-killer we know and love we need to break the habit and stop automatically reaching for glyphosate. Introduce paraquat products when dealing with smaller weeds and for a long-term solution, farm with a very low seed bank.

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

VIDEOS

WATCH: Don't cut the rate.

WATCH: Don't automatically reach for glyphosate.

WATCH: Manage spray drift.

WATCH: Plant clean seed into clean paddocks with clean borders.

WATCH: Best results with double knock tactic.

7. Carefully manage spray events.

It's important to set up your spray gear to maximise the amount of herbicide applied directly to the target. This makes the spray application more cost effective by killing the maximum number of weeds possible and protects other crops and pastures from potential damage and/or contamination.

Spray technology has improved enormously in the last ten years making it far easier for growers to get herbicides where they need to be. Also, many herbicide labels specify the droplet spectrum to be used when applying the herbicide (so take the time to read the label beforehand).

As a general rule, medium to coarse droplet size combined with higher application volumes provides better coverage of the target. Using a pre-orifice nozzle slows droplet speed so they are less prone to bouncing off the target.

Using oil-based adjuvants with air-induction nozzles can reduce herbicide deposition by reducing the amount of air in the droplets. These droplets then fail to shatter when they hit the target, which increases droplet bounce.

- 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.

8. Plant clean seed into clean paddocks with clean borders.

Keep it clean! With herbicide resistance on the rise, planting clean seed into clean paddocks with clean borders has become a top priority.

Controlling weeds is easiest before the crop is planted, so be sure to plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant ones.

Introducing systems that increase farm hygiene will also prevent new weed species and resistant weeds. These systems could include crop rotations, reducing weed burdens in paddocks or a harvest weed seed control such as the HSD or windrow burning.

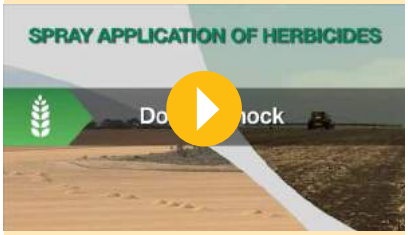
Lastly, roadsides and fence lines are often a source of weed infestations. Weeds here set enormous amounts of seed because they have little competition, so it's important to control these initial populations by keeping clean borders.

- 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.

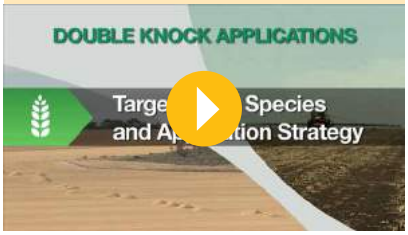
VIDEOS

WATCH: Double knock application – a Grower's Experience.

WATCH: Spray application of herbicides – Double Knock.



WATCH: Double knock applications - target weed species & application strategy



MORE INFORMATION

CropLife Australia

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

Cotton Info Weedpak

9. Use the double-knock technique.

What's better than an attack on weeds? A second one. Come at them with a different strategy and any survivors left over don't stand a chance, that's the beauty of the double-knock.

To use the double-knock technique, combine two weed control tactics with different modes of action, on a single flush of weeds. These two "knocks" happen in sequential strategies; the second application designed to control any survivors from the first.

One such strategy is the glyphosate/paraquat double-knock. These two herbicides use different MOAs to eliminate weeds and so make an effective team when paired up. When using this combination ensure the paraquat rate is high.

The best time to initiate a glyphosate/paraquat double-knock is after rainfall. New weeds will quickly begin to germinate and should be tackled at this small stage.

10. Employ crop competitiveness to combat weeds.

Help your crops win the war against weeds by increasing their competitiveness against them:

- Consider narrow row spacing and seeding rates.
- Consider twin-row seeding points.
- Consider east-west crop orientation.
- Use barley and varieties that tiller well.
- Use high-density pastures as a rotation option.
- Consider brown manure crops.
- Rethink bare fallows.

If you think you have resistant weeds

When resistance is first suspected, it is recommended that growers contact their local agronomist.

The following steps are then recommended.

Consider the possibility of other common causes of herbicide failure by asking:

1. Was the herbicide applied in conditions and at a rate that should kill the target weed?
2. Did the suspect plants miss herbicide contact or emerge after the herbicide application?
3. Does the pattern of surviving plants suggest a spray miss or other application problem?
4. Has the same herbicide or herbicides with the same mode of action been used in the same field or in the general area for several years?
5. Has the uncontrolled species been successfully controlled in the past by the herbicide in question or by the current treatment?
6. Has a decline in the control been noticed in recent years?
7. Is the level of weed control generally good on the other susceptible species?

If resistance is still suspected:

1. Contact your local agronomist for advice on sampling suspect plants for testing of resistance status.
2. Ensure all suspect plants do not set any seed.
3. If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread. [41]

41 QLD DAFF (2015) Stopping herbicide resistance in Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

VIDEOS

WATCH: Learn to think outside the drum.

WATCH: Crop Competition – increasing wheat seeding rate.

WATCH: Crop competition—Row Spacing.

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
  https://www.csu.edu.au/weedresearchgroup/herbicide-resistance
  CSU plant testing application form.
- Plant Science Consulting P/L
  22 Linley Avenue, Prospect
  SA 5082, Australia
  info@plantscienceconsulting.com.au
  Phone: 0400 66 44 60

Insect control

Key messages:

- Know the enemy: accurate identification of beneficial and pest species is fundamental.
- Know the control thresholds for pests in your crops.
- Monitor pest populations prior to seeding, during the growing season and after control treatments.
- Use appropriate and consistent sampling methods.
- Select appropriate control methods.
- Insects are not usually a major problem in cereals but sometimes they build up to an extent that control may be warranted.
- Integrated Pest Management (IPM) strategies encompass chemical, cultural and biological control mechanisms to help improve pest control and limit damage to the environment.

Insect pests cause grain crop losses totaling hundreds of millions of dollars across Australia every year, so reducing the potential for pest damage is a high priority for growers. Insects are not usually a major problem in 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.

> *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

7.1 Potential insect pests

Insect and other arthropod pests that can pose a problem in wheat include blue oat mite (*Penthaleus* spp.), redlegged earth mite (*Halotydeus destructor*), Bryobia mites (*Bryobia* spp.), *Balaustium* mite, cutworms, aphids, slugs, snails, earwigs, millipedes, slaters, armyworms, pasture webworm, pasture cockchafers, grass anthelids, lucerne flea (*Sminthurus viridis*), leaf hoppers and locusts. Mice may also cause damage.

Stay informed about invertebrate pest threats throughout the winter growing season by subscribing to the South Australian Research and Development Institute's (SARDI) PestFacts South Australia newsletter and cesar's PestFacts south eastern newsletter. Subscribers to cesar's newsletter also benefit from special access to the company's extensive insect gallery, which can be used to improve skills in identifying pest and beneficial insects.

Table 1: *Situations and insect pest risk for winter cereals.*

High risk	Moderate risk	Low risk
Soil insects, slugs and snails		
Some crop rotations increase the likelihood of soil insects. Cereal sown into a long-term pasture phase. High stubble loads. Above average rainfall over summer-autumn. History of soil insects, slugs and snails. Summer volunteers and brassica weeds will increase slug and snail numbers. Cold, wet establishment conditions exposes 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 history of slugs. Increased sowing rate to compensate for seedling loss caused by establishment pests.	Slugs and snails are rare on sandy soils
Earth mites		
Cereals adjacent to long term pastures may get mite movement into crop edges. Dry or cool, wet conditions that slows crop growth increases crop susceptibility to damage. History of high mite pressure.	Leaf curl mite populations (they transmit wheat streak mosaic virus) can be increased by grazing and mild wet summers.	Seed dressings provide some protection, except under extreme pest pressure.
Aphids		
Higher risk of barley yellow dwarf virus disease transmission by aphids in higher rainfall areas where grass weeds are present prior to sowing. Wet summer and autumn promotes survival of aphids on weed and volunteer hosts.	Wet autumn and spring promotes the growth of weed hosts (aphids move into crops as weed hosts dry off). Planting into standing stubble can deter aphids landing. Use of seed dressings can reduce levels of virus transmission and delay aphid colonisation. Use of SPs and OPs to control establishment pests can kill beneficial insects and increase the likelihood of aphid survival.	Low rainfall areas have a lower risk of BYDV infection. High beneficial activity (not effective for management of virus transmission).

High risk	Moderate risk	Low risk
Armyworm		
Large larvae present when the crop is at late ripening stage.	High beneficial insect activity (particularly parasitoids). Rapid crop dry down.	No armyworm present at vegetative and grain filling stages.

Source: IPM Guidelines

Table 2: *Impact of insect according to crop stage.*

	Crop stage			
Pest	**Emergence**	**Vegetative**	**Flowering**	**Grainfill**
Wireworms	Damaging	Present		
Cutworm	Damaging			
Black headed cockchafer	Damaging	Present		
Earth mites	Damaging	Present		
Slugs, snails*	Damaging			
Brown wheat mite		Damaging		
Aphids	Present	Damaging	Present	Present
Armyworm		Present	Present	Damaging
Helicoverpa armigera				Damaging

* Snails are also a grain contaminant at harvest

Source: IPM Guidelines

The SARDI Entomology Unit provides an insect identification and advisory service. The Unit identifies insects to the highest taxonomic level for species where this is possible and can also give farmers biological information and guidelines for control. [1]

Table 3 provides an identification key for common crop pests.

Table 3: *Crop damage pest identification key for the southern region. Pests labelled with an asterix (*) are relevant in south-eastern Australia only.*

Damage to crop	Pest
Leaves or plants cut off and lying on the ground or protruding from small holes next to plants; brown caterpillars (up to 15 mm long) with black heads, present in web-lined tunnels; wheat or barley seeded into grassy pasture paddocks.	Webworm
Leaves or plants cut off and lying on the ground or protruding from small holes next to plants. Slender larvae, up to 35 mm long, construct silk-lined tunnels that protrude above ground to form chimneys.	Pasture tunnel moth*
Leaves or plants cut off and lying on the ground or protruding from small holes next to plants. Larvae are brown with black and yellow marking, covered in tufts of stout hairs and can grow up to 50 mm in length.	Grass anthelid*
Leaves of young seedlings fed upon or damaged; in severe cases seedlings are ring-barked at ground level causing them to drop. Adults are 3–5 mm long, round and dull brown resembling small clods of dirt.	Mandalotus weevil*

1 PIRSA (2015) Insect diagnostic service. Primary Industries and Regions South Australia, June 2015, http://pir.sa.gov.au/research/research_specialties/sustainable_systems/entomology/insect_diagnostic_service

Damage to crop	Pest
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 eight-legged (nymphs have six legs) velvety black or brown crawling creatures with orange-red legs, found on plants or on soil surface at the base of plants.	Redlegged earth mite, blue oat mite, Balaustium mite
Plants stunted and dying at emergence and up to tillering; chewing of seed and stem below ground; white legless larvae up to 7 mm long present near point of attack.	Spotted vegetable weevil or Desiantha weevil
Plants stunted or dying; roots eaten; slow-moving, soft bodied insects usually in a 'C' shape, cream-coloured apart from head and visible gut contents; found near roots.	Cockchafers, African black beetle
Plants yellowing and withering; on light soils mostly on coastal plain; stems underground shredded; presence of elongated, cylindrical insects up to 75 mm long, first pair of legs adapted for digging.	Sandgropers*
Green and straw-coloured insect droppings like miniature square hay bales on ground; cereal heads on ground; some chewing of leaves and seed heads of weeds such as ryegrass. Smooth, fat caterpillars up to 40 mm long, with three stripes on collar behind head; found at base of plants or climbing plants.	Armyworm
Seeds chewed but heads not severed; caterpillars up to 40 mm long, sparsely covered with small bumps and bristles, may be various shades of green, yellow, orange or brown; found on seed heads.	Native budworm and related species
Presence of many grey-green insects approx. 2 mm long, with or without wings, on upper portions of stem. If heavy infestations, plants stunted; sticky with secretions, possibly black mould growing on secretions.	Aphids
Damage in fine pale dots in wriggly or zigzag lines. Yellow to green, 3 mm long wedge-shaped sucking insects that jump sideways when disturbed.	Leafhoppers

Source: I Spy.

7.2 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.

IPM uses a combination of biological, cultural and chemical control methods to reduce insect pest populations. A key aim of IPM is to reduce reliance on insecticides as the sole and primary means of pest control. IPM can improve growers' profitability while reducing environmental damage and limiting the risk of on-farm pesticide exposure.

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.

Insecticide choices

- RLEM, BOM, and other mite species can occur in mixed populations. Determine species composition before making decisions as they have different susceptibilities to chemicals.
- Establishment pests have differing susceptibilities to insecticides (SPs, OPs in particular). Be aware that the use of some pesticides may select for pests that are more tolerant.

Insecticide resistance

- RLEM has been found to have high levels of resistance to synthetic pyrethroidssuch as bifenthrin and alpha-cypermethrin.
- *Helicoverpa armigera* has historically had high resistance to pyrethroids and the inclusion of NPV is effective where mixed populations of armyworm and helicoverpa occur in maturing winter cereals. [2]

VIDEOS

WATCH: Integrated Pest Management.

7.2.1 Insect sampling methods

Monitoring for insects is an essential part of successful integrated pest management 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 a knowledge of and the ability to identify the insects present, but also good sampling and recording techniques and a healthy dose of common sense.

Factors that contribute to quality monitoring

- **Knowledge of likely pests/beneficials and their life cycles** is essential when planning your monitorng 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.

2 IPM Guidelines. Winter cereals. GRDC and DAFF, http://ipmguidelinesforgrains.com.au/crops/winter-cereals/

- **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 a representative portion of the crop has been monitored since pest activity is often patchy. Having defined 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 regarding time constraints and distance covered.
- **Balancing random sampling with areas of obvious damage** is a matter of common sense. Random sampling aims to give a good overall picture of what is happening in the field, but any obvious hot-spots should also be investigated. The relative proportion of hotspots in a field must be kept in perspective with less heavily infested areas.

Keeping good records

Accurately recording the results of sampling is critical for good decision making and being able to review the success of control measures (Figure 1). Monitoring record sheets should show the following:

- numbers and types of insects found (including details of adults and immature stages);
- size of insects—this is particularly important for larvae;
- date and time; and
- crop stage and any other relevant information (e.g. row spacings, weather conditions, and general crop observations).

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 photographs for later reference.

Site: Camerons
Date: 15/9/06
Row spacing: 75cm

Sample (1 m row beat)	VS	S	M	L
1	8	5	1	0
2	1	1	1	0
3	3	3	0	1
4	3	2	1	0
5	2	6	0	0
Average		3·4	0·6	0·2
Adjust for 30% mortality (S*0.7)	(3·4×0·7) = 2·4			
Mean estimate of larval number (Adjusted S)+M+L	2·4 0·6 0·2 = 3·2			

Adjust for row spacing divide by row spacing (m) $\frac{3.2}{0.75}$ 4·2 Density Estimate per square metre

Figure 1: *An example of a field check sheet for chickpeas, showing adjustments for field mortality and row spacings.*

Source: DAFF

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; and
- any other relevant details.

Sampling methods

Beat sheet

A beat sheet is the main tool used to sample row crops for pests and beneficial insects (Photo 1). 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 between 1.3–1.5 m wide by 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.

How to use the beat sheet:

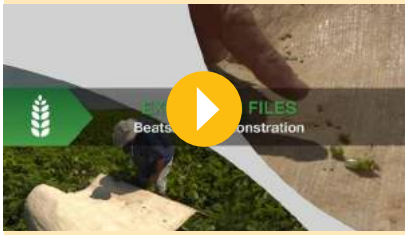
- Place the beat sheet with one edge at the base of plants in the row to be sampled.
- Drape the other end of the beat sheet over the adjacent row. This may be difficult in crops with wide row spacing (one metre or more) and in this case spread the sheet across the inter-row space and up against the base of the next row.
- Using a one-metre 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 one-metre long lengths 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).
- The more samples that are taken, the more accurate is the assessment of pest activity, particularly for pests that are patchily distributed such as pod sucking bug nymphs.

When to use the beat sheet:

- Crops should be checked weekly during the vegetative stage and twice weekly from the start of budding onwards.
- 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 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.

VIDEOS

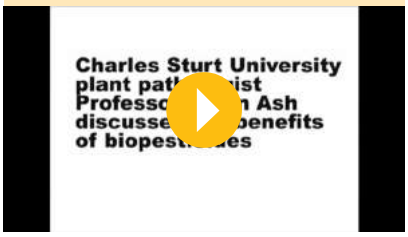
WATCH: GCTV16: Extension files—IPM Beatsheet Demo.



WATCH: How to use a sweep net to sample for insect pests.

WATCH: GRDC's Insect ID App.

WATCH: Biopesticides emerge as an alternative cropping tool.



- Using the beat sheet to determine insect numbers is difficult when the field and plants are wet.

While 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 more minor pests. Visual sampling will also assist in finding eggs of pests and beneficial insects.

Most thresholds are expressed as pests per square metre (pests/m^2). Hence, insect counts in crops with row spacing less than one metre 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 0.75 m (75 cm) row spacing, 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 going in terms of average growth stage, pod retention 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 (Photo 1). 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. [3]

Photo 1: *Sweep-netting for insects (left) and use of a beatsheet (right).*

Source: DAFWA and The Beatsheet

It has been found that, while narrow row spacing has been increasingly recommended as a means to increase crop yields, opting for the "wider" of the

3 DAFF (2012) Insect monitoring techniques for field crops, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/insect-monitoring

narrow row spacing options had the most positive outcomes in terms of insect detection and management. [4]

For pest identification see the A-Z pest list or consult the GRDC Insect ID: The Ute Guide.

The Insect ID Ute Guide (Figure 2) is a comprehensive reference guide for insect pests commonly affecting broadacre crops across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored and other pests that they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [5]

Figure 2: *GRDC's Ute Guide for insect identification is available as an app.*

Source: Grains Research and Development Corporation

App features:

- region selection
- predictive search by common and scientific names
- compare photos of insects side by side with insects in the app
- identify beneficial predators and parasites of insect pests
- opt to download content updates in-app to ensure you're aware of the latest pests affecting crops for each region
- ensure awareness of international bio-security pests.

Insect ID, The Ute Guide is available on Android and iPhone.

Beneficials

Beneficial insects and other invertebrates ("beneficials") offer a variety of ecosystem services that are essential within agricultural environments and it is important to conserve and promote them as far as is practical within the constraints of controlling for major crop pests. For example, many beneficial species are important in soil health and nutrient cycling. Some beneficial invertebrates can also take the form of "natural enemies" of pest species and play a major role in the suppression of pest populations within our cropping systems. [6]

MORE INFORMATION

IPM Guidelines website.

IPM Guidelines for Monitoring tools and techniques.

4 GRDC (2016) What row spacing increases yield but decreases pest and disease pressure? Grains Research and Development Corporation, July 2016, https://grdc.com.au/Media-Centre/Hot-Topics/What-row-spacing-increases-yield-but-decreases-pest-and-disease-pressure

5 GRDC Apps. Grains Research and Development Corporation, https://grdc.com.au/Resources/Apps

6 GRDC (2011) Dont forget the good guys—recognising and identifying beneficial insects in your paddock. GRDC Update Papers. Grains Research and Development Corporation, September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54t/nax0b3j

7.3 Russian wheat aphid

Key points:

- Russian wheat aphid (RWA) is found in all major cereal production regions around the world, however it has never been found in Australia before now.
- It is a major pest of cereal crops that injects toxins into the plant during feeding which retards growth and with heavy infestations, kills the plant.
- Affected plants will show whitish, yellow and red/purple leaf markings and rolling leaves.
- Russian wheat aphid is approximately 2 mm long, pale yellowish green with a fine waxy coating. The body is elongated compared with other cereal aphid species (Photo 2).

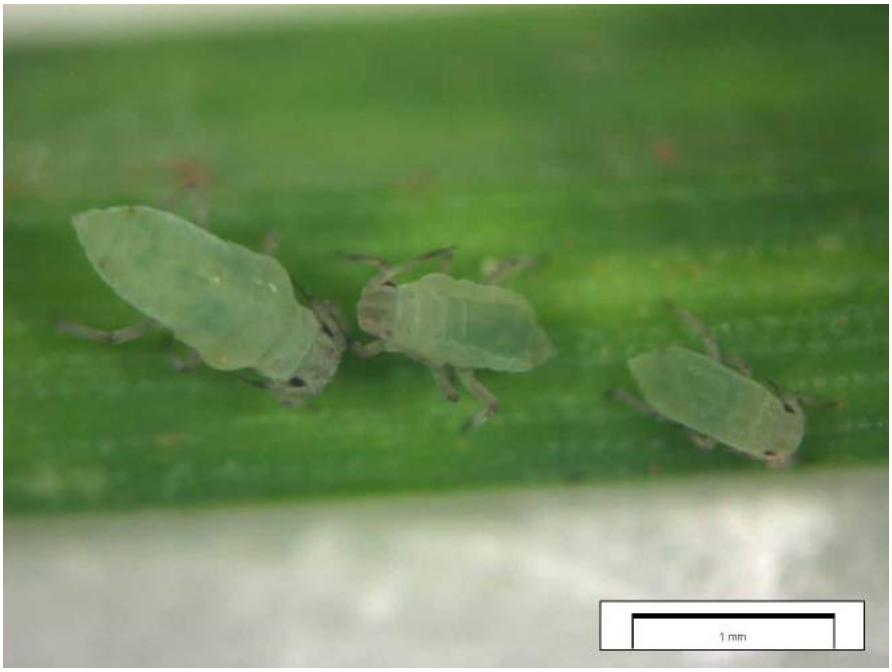


Photo 2: *The Russian wheat aphid (Diuraphis noxia).*

Photo: Michael Nash. Source: GRDC

According to South Australian Research and Development Institute (SARDI) entomologists, RWA is being regularly found in early-sown crops or those sown into paddocks containing volunteer cereals. In order of host preference based on overseas data, RWA tends to favour: barley, durum wheat, bread wheat, triticale, cereal rye and oats. [7]

Grain growers and advisers across the southern region are urged to monitor cereal paddocks closely for signs of damage caused by RWA.

If needed, growers should also implement a considered management strategy to control the pest.

It was recently declared not technically feasible to eradicate RWA from south-east Australia by the National Management Group (NMG) after it was first identified in a wheat crop at Tarlee in South Australia's mid north on May 13, 2016.

Since then, the aphid has been identified in many cropping regions across South Australia (Figure 4) and in the Wimmera and Mallee regions of Victoria.

In Victoria, 48 crop samples have been confirmed for RWA infestation (Figure 3):

7 Farming ahead (2016) Monitor RWA numbers closely over winter, http://www.farmingahead.com.au/articles/1/12169/2016-06-29/cropping/monitor-rwa-numbers-closely-over-winter

- 44 confirmed samples in an area bounded by Edenhope, Stawell, Bendigo, Echuca, Swan Hill, Manangatang, Patchewollock and the South Australian border.
- One sample to the west of Ararat; one sample to the west of Daylesford; one sample to the west of Werribee; and one sample to the south of Inverleigh (west of Geelong).

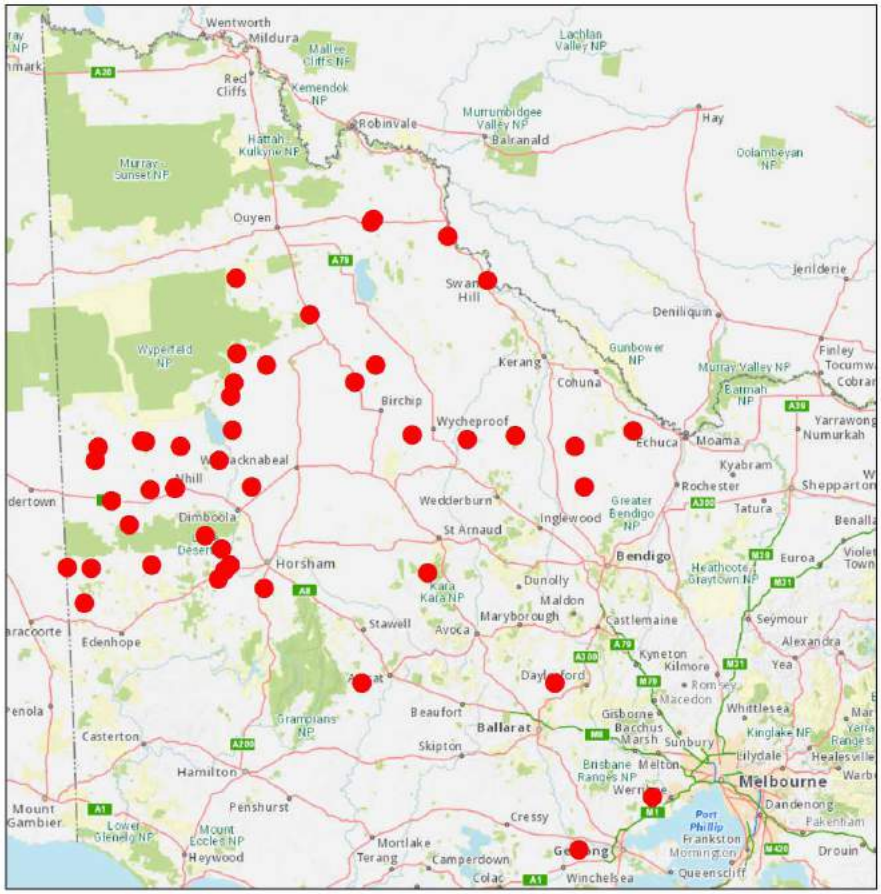


Figure 3: *Confirmed instances of Russian Wheat Aphid in Victoria.*

Source: AgVic

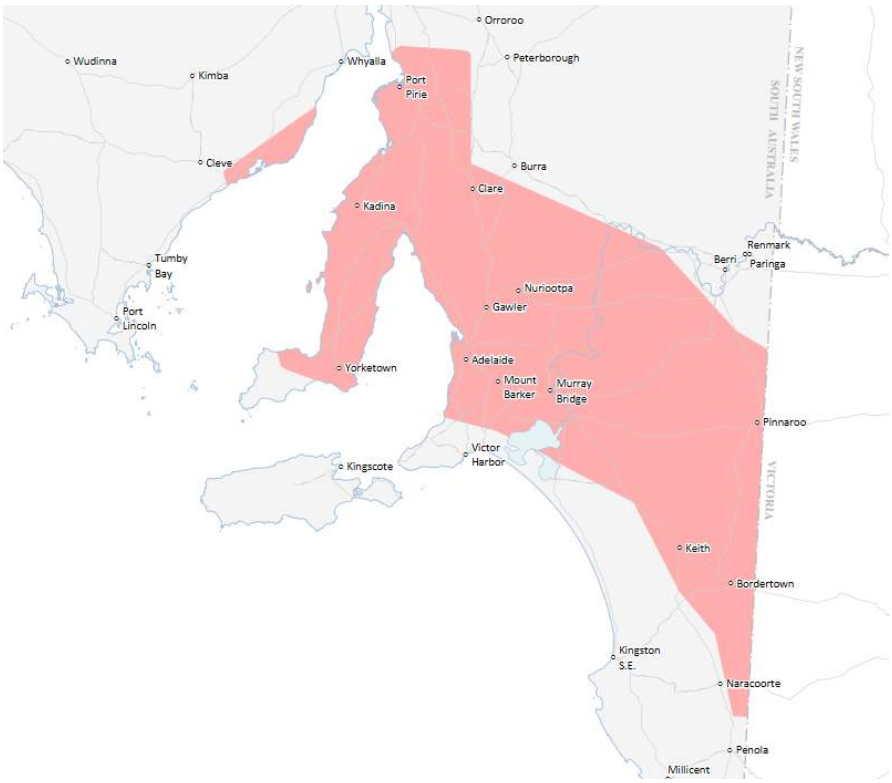


Figure 4: *Area affected by Russian Wheat Aphid in South Australia.*

Source: PIRSA

Following this declaration, experts are calling on growers and advisers to find, identify, consider aphid numbers and economic thresholds and enact a management strategy (FITE) if needed.

RWA is a major pest of cereal crops worldwide. It is easily spread by the wind and on live plant material.

It is asexual, meaning it does not need males and females to breed. The aphid takes about three weeks in winter and 10 to 14 days in mid-spring to reach maturity. It then continues to produce about two nymphs on a daily basis for two to four weeks, totalling 30—60 nymphs produced per female. This means it has a great capacity to increase numbers rapidly.

Further research is required to determine the impact of local environmental factors on RWA population dynamics. [8]

7.3.1 Damage caused by RWA

RWA differs from other common cereal aphid species in that it injects salivary toxins into the leaf of the host plant during feeding, which kills the photosynthetic chloroplasts and causes chlorosis and necrosis of the infested leaves. This retards growth and, in cases of heavy infestation, kills the plant. The effect of these toxins is localised and hence only infested leaves will show symptoms. Once the RWA infestation is controlled, new leaf growth is unaffected. [9]

Yield losses are proportionate to RWA abundance, measured as either percentage of plants infested or aphid numbers per shoot. According to overseas data, losses of 1 t/h occurred in plants 95% infested with RWA at GS59. In another overseas study,

8 Farming ahead (29 June 2016) Monitor RWA numbers closely over winter, http://www.farmingahead.com.au/articles/1/12169/2016-06-29/cropping/monitor-rwa-numbers-closely-over-winter

9 Farming ahead (29 June 2016) Monitor RWA numbers closely over winter, http://www.farmingahead.com.au/articles/1/12169/2016-06-29/cropping/monitor-rwa-numbers-closely-over-winter

losses increased from 18% with 15-20 aphids per shoot to 79% with 185–205 aphids per shoot. [10]

7.3.2 Where to look and what to look for

According to South Australian Research and Development Institute (SARDI) entomologists, RWA is being regularly found in early-sown crops or those sown into paddocks containing volunteer cereals. There are also a number of grass weed and pasture hosts of RWA, including: barley grass, brome grass (particularly favourable, based on overseas information), fescue, ryegrass, wild oats, phalaris and couch grass.

Symptoms of RWA damage include longitudinal rolling of leaves where the aphids shelter and whitish, yellowish to pink-purple chlorotic streaks along the length of the leaves. These symptoms can often be confused with nutrient deficiency or herbicide damage from bleaching herbicides such as diflufenican.

RWA are approximately two millimetres long and a pale yellowish green colour with a fine, waxy coating. The lack of visible cornicles and elongated body distinguishes RWA from common cereal aphid species.

RWA can be confused with the rose grain aphid; however, it differs due to its dark or black eyes, double short "tails" (caudal processes), short antennae and apparent lack of cornicles (Figure 5).

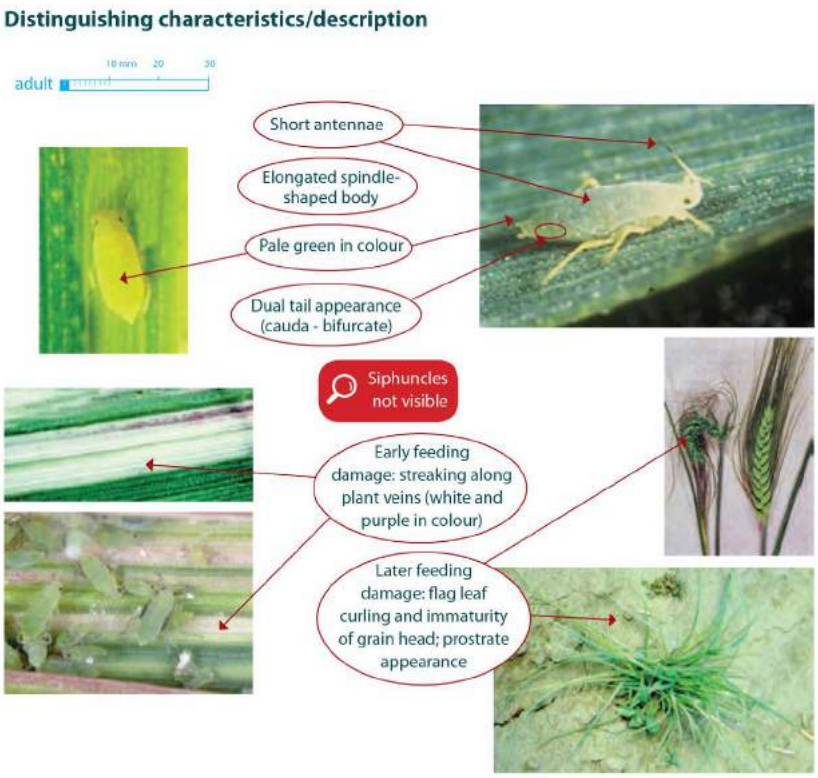


Figure 5: *Russian wheat aphid, distinguishing characteristics.*

Photo: Frank Peairs. Source: GRDC

Growers are encouraged to work with their agronomist or seek expert advice from an entomologist to help positively identify RWA if they are unsure.

State agriculture departments are keen to take samples of RWA in order to build up scientific information about the pest and sample different populations.

10 A Lawson (2016) Monitor RWA numbers closely over winter, https://grdc.com.au/Media-Centre/GRDC-E-Newsletters/Paddock-Practices/Monitor-RWA-numbers-closely-over-winter

Measures to increase the likelihood of RWA detection

- Target early sown cereal crops and volunteer cereals (and brome grass if present), particularly along crop edges.
- Follow a repeatable sampling pattern, which targets early sown and volunteer plants. A perimeter search and a 'W' shaped search pattern through each paddock will give a consistent sampling effort
- Look for RWA symptomatic plants:
- Rolling of terminal and sub-terminal leaves (Growth stage 20 and above).
- Longitudinal whitish to pink-purplish streaking of leaves (Growth stage 20 and above, Photo 3).
- Deformed "goose-neck" head as result of awn trapped by unrolled flag leaves (Growth stage 50 and above, Photo 4).

Photo 3: *Plants damaged by toxins from feeding Russian wheat aphid (Diuraphis noxia), showing stunting and longitudinal striping on tightly rolled leaves.*

Source: FAO

Photo 4: *Fish hook" deformation of a cereal head (right), caused by feeding Russian wheat aphid compared to a normal cereal head (left).*

Source: FAO

Where to find the RWA

Search within:

- Rolled leaves, particularly in the leaf base (Photo 5).
- Leaf sheaths.
- In high numbers RWA are being found active on exposed parts at base of plants.

- At low densities, plant beating has proven successful for detection. [11]

Photo 5: *Colony of Russian wheat aphids.*

Photo: Frank Peairs. Source: PIRSA

MORE INFORMATION

Taking and submitting samples for identification.

7.3.3 Thresholds for control

While registered chemical control tactics will be important in managing infestations of RWA, growers are encouraged to consider international economic thresholds (below) as a guide for when to spray for the pest.

Whilst the economic thresholds for control still need to be determined under Australian conditions, aphid numbers should be a key consideration before making the decision to spray. The key message is to not implement prophylactic insecticide applications and to reconsider the need to spray where RWA is only present in very low numbers.

Current international advice suggests an economic threshold of 20% of plants infested up to the start of tillering and 10% of plants infested thereafter. These thresholds serve as a guide and need to be considered based upon the individual situation. The decision to spray should be based upon a wide range of factors including:

- Aphid numbers.
- Crop growth stage and time of season.
- Crop yield potential.
- Cost of the control option to be employed.
- Beneficial insect populations.
- Yield loss under Australian conditions.
- Forecast weather conditions.
- Other insect pest species present.

In the majority of cases identified in SA and Victoria to date, RWA has been present in very low numbers and infestations have been well below international economic thresholds. Regular monitoring of aphid numbers through winter and spring will be required to ensure appropriate control measures may be implemented as required. Overseas data indicates that RWA is susceptible to heavy winter rainfall, and the combination of cold and wet weather will help check its build-up during mid-winter.

11 PIRSA (2016) Russian wheat aphid—paddock surveillance, http://www.pir.sa.gov.au/biosecurity/plant_health/exotic_plant_pest_emergency_response/russian_wheat_aphid

To ensure protection of the major yield contributing leaves it is most important to control RWA below threshold levels from the start of stem elongation, through flag leaf development and ear emergence. As a result, vigilant monitoring for RWA is encouraged during these crop stages (growth stage 30–60), and should continue through flowering to dough development. [12]

7.3.4 Management of RWA

Control options

An emergency Australian Pesticides and Veterinary Medicines Authority (APVMA) permit (PER82792) has been issued for the use of products containing 500 g/L chlorpyrifos (rate: 1.2 L/ha), with a LI700 surfactant (rate: 240 ml/ha), and products containing 500 g/kg pirimicarb (rate: 200-250 g/ha) to control RWA in winter cereals.

An Australian Pesticides and Veterinary Medicines Authority (APVMA) permit (PER82304) has been issued for the use of products containing 600 g/L IMIDACLOPRID as their only active constituent. Application rate 120 mL product / 100 kg seed. This is for seed treatment only for the control of RWA in winter cereals.

The permit must be read and understood by all persons operating in accordance with it.

The Australian Pesticides and Veterinary Medicines Authority (APVMA) have issued an emergency permit (82792) for growers to control Russian wheat aphid.

- Permit 82792
- Permit 82792

A new permit has been issued by the Australian Pesticides and Veterinary Medicines Authority (APVMA) for growers to control Russian wheat aphid during seed treatment over winter.

- Permit 82304
- Permit 82304

Chemical users must read and understand all sections of chemical labels and permits prior to use. There are numerous statements (e.g. DO NOT statements) on product labels that are critical in the managing risks associated with the use of chemicals. Examples of such statements include:

- DO NOT spray any plants in flower while bees are foraging.
- DO NOT re-apply to the same crop within seven days (unless specifically recommended in the directions for Use).
- DO NOT apply if heavy rains or storms that are likely to cause surface runoff are forecast in the immediate area within two days of application.
- DO NOT allow animals or poultry access to treated area within three days of application.

Bees

As for all field chemical use, it is recommended that users consider the risks of chemical use to bees that may be present in the local area. Chemical users are encouraged to contact hive owners as soon as possible so that they can take appropriate steps to minimise the risks to their hives.

Contact details can generally be found on the hive(s) or you can contact the land owner on which the hives are located.

General instructions

- Read and follow the APVMA permit and labels of associated chemical products.

MORE INFORMATION

Russian wheat aphid—a new pest for Australian cereal crops

Ramp up monitoring for Russian wheat aphid

Monitor RWA numbers closely over winter

Russian wheat aphid—Plant health Australia

Russian wheat aphid reporting sheet (PDF, 279.7 KB)

Exotic Pest Alert: Identification of Russian wheat aphid and associated damage

PIRSA Russian wheat aphid—Paddock decontamination protocol (DOC, 197 KB)

RWA Distribution Map

12 A Lawson (2016) Monitor RWA numbers closely over winter, https://grdc.com.au/Media-Centre/GRDC-E-Newsletters/Paddock-Practices/Monitor-RWA-numbers-closely-over-winter

VIDEOS

WATCH: GCTV20: Russian wheat aphid—recommendations for ongoing treatment.

WATCH: Integrated pest management to combat the Russian wheat aphid.

- Ensure all DO NOT statements and relevant Withholding Periods, Export Slaughter Intervals (ESIs) and Export Grazing Interval (EGIs) are observed.
- Adopt best-practice farm hygiene procedures to retard the spread of the pest between fields and adjacent properties.
- Keep traffic out of affected areas and minimise movement in adjacent areas. [13]

7.4 Other Aphids

Aphids are usually regarded as a minor pest of winter cereals, but in some seasons, they can build up to very high densities.

Four different species of aphid can infest winter cereals:

1. Oat or wheat aphid
2. Corn aphid
3. Rose-grain aphid
4. Rice root aphid

Aphids are a group of soft-bodied bugs commonly found in a wide range of crops and pastures. Identification of crop aphids is very important when making control decisions. Distinguishing between aphids can be easy in the non-winged form but challenging with winged aphids. See a pictorial guide to distinguishing winged aphids.

7.4.1 Oat or wheat aphid

The oat aphid is a relatively common aphid that is most prevalent in wheat and oats. This aphid has an olive green body with a characteristic rust-red patch on the end of the abdomen. Oat aphids are an important vector of barley yellow dwarf virus (BYDV). They can affect cereals by spreading BYDV as well as by direct feeding damage to plants when in sufficient numbers. When populations exceed thresholds, the use of targeted spraying with selective insecticides is recommended.

The oat aphid is an introduced species that is a common pest of cereals and pasture grasses. They are widespread and found in all states of Australia. Oat aphids typically colonise the lower portion of plants, with infestations extending from around the plant's base, up on to the leaves and stems.

Oat aphids vary in colour from olive-green to greenish black and are usually identifiable by a dark rust-red patch on the tip of the abdomen, although under some conditions this is not apparent. Adults are approximately 2 mm long, pear-shaped and have antennae that extend half the body length (Figure 6). Adults may be winged or wingless and tend to develop wings when plants become overcrowded or unsuitable. [14]

13 Agriculture Victoria (2016) RWA treatment factsheet. http://agriculture.vic.gov.au/__data/assets/word_doc/0017/321164/Final-RWA-Treatment-Factsheet.docx-.docx

14 P Umina, S Hangartner (2015) Oat aphid. Cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

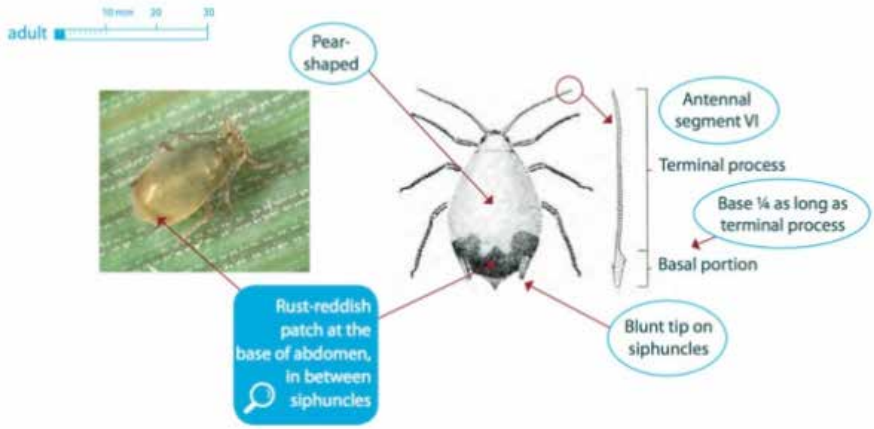


Figure 6: *Distinguishing characteristics of oat or wheat aphids.*

Source: Bellati et al. (2012), in Cesar

7.4.2 Corn aphid

Corn aphids are introduced, and are a relatively minor pest of cereal crops. They attack all crop stages but most damage occurs when high populations infest cereal heads. Corn aphids are most prevalent in years when there is an early break to the season followed by mild weather conditions in autumn. Corn aphids transmit a number of plant viruses, which can cause significant yield losses.

Corn aphids are light green to dark green, with two darker patches at the base of each cornicle (siphuncle). Adults grow up to 2 mm long, have an oblong-shaped body and antennae that extend to about a third of the body length (Figure 7). The legs and antennae are typically darker in colour.

Nymphs are similar to adults but smaller in size and always wingless, whereas adults may be winged or wingless. [15]

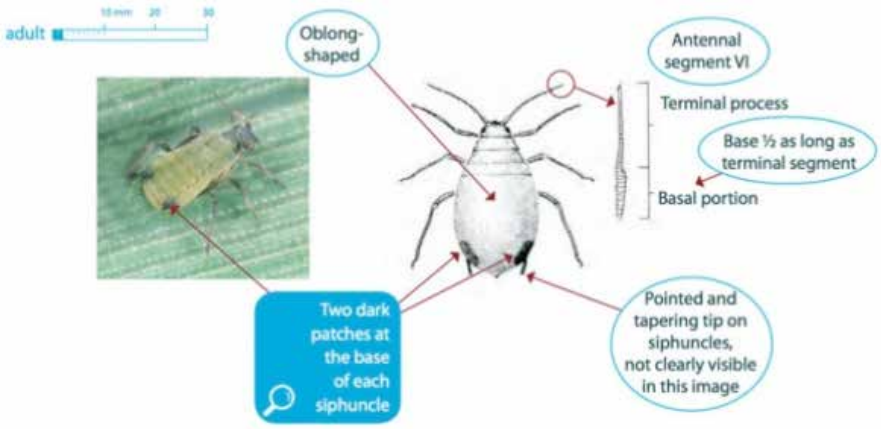


Figure 7: *Distinguishing characteristics of corn aphids.*

Source: Bellati et al. (2012) in Cesar

7.4.3 Rose-grain aphid

Rose-grain aphids are an introduced species that has been recorded in SA, Victoria, Tasmania, NSW and Queensland.

15 P Umina, S Hangartner (2015) Oat aphid. Cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Corn-aphid

Adults and nymphs are sapsuckers. Under heavy infestations, plants may turn yellow and appear unthrifty. Rose-grain aphids can spread barley yellow dwarf virus in wheat and barley.

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 (Photo 6). 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. Because of its distinctive colour, it is unlikely to be confused with other aphids.

Photo 6: *Adult Rose-grain aphid with nymphs.*

Source: QDAFF

7.4.4 Conditions favouring aphid development

Aphids can be found all year round, often persisting on a range of volunteer grasses and self-sown cereals during summer and early autumn. Winged aphids fly into crops from grass weeds, pasture grasses or other cereal crops, and colonies of aphids start to build up within the crop.

Aphids are most prevalent on cereals in late winter and early spring. High numbers often occur in years when there is an early break in the season and mild weather in autumn and early winter provide favourable conditions for colonisation and multiplication.

- Oat aphid—basal leaves, stems and back of ears of wheat, barley, oats.
- Corn aphid—inside the leaf whorl of the plant; cast skins indicate their presence; seldom on wheat or oats.
- Grain aphid—colonises the younger leaves and ears of wheat, oats and barley;
- Rose-grain aphid—underside of lower leaves and moves upwards as these leaves die. [16]

Aphids can reproduce both asexually and sexually, however, in Australia, the sexual phase is often lost. Aphids reproduce asexually whereby females give birth to live young.

Temperatures during autumn and spring are optimal for aphid survival and reproduction. During these times, the aphid populations may undergo several generations. Populations peak in late winter and early spring; development rates are particularly favoured when daily maximum temperatures reach 20–25°C.

16 IPM Guidelines (2016) Aphids in winter cereals, http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-winter-cereals/

Young wingless aphid nymphs develop through several growth stages, moulting at each stage into a larger individual. Plants can become sticky with honeydew excreted by the aphids. When plants become unsuitable or overcrowding occurs, the population produces winged aphids (alates), which can migrate to other plants or crops.

7.4.5 Damage caused by aphids

Aphids can impair growth in the early stages of crop and prolonged infestations can reduce tillering and result in earlier leaf senescence. Some research indicates that aphid infestations can reduce yield by ~10% on average. Infestations during booting to milky dough stage, particularly where aphids are colonising the flag leaf, stem and ear, result in yield loss, and aphid infestations during grainfill may result in low protein grain. As aphids may compete with the crop for nitrogen, crops grown with marginal levels of nitrogen can be more susceptible to the impact of an aphid infestation.

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 Barley yellow dwarf virus in wheat and barley. [17]

Aphids can damage crops by spreading viruses or causing direct damage when feeding on plants. Feeding damage generally requires large populations, but virus transmission can occur before aphids are seen to be present. Pre-emptive management is required to minimise the risk of aphids and their transmission of viruses. Viruses are widespread in cereal, pulse and oilseed crops throughout southern and western Australia and can cause significant economic losses, especially when extensive infection occurs in early crop growth. Aphids are the principal, but not sole, vectors of viruses in crops; some are also transmitted in seed. A few aphids can cause substantial damage if they are spreading viruses, especially early in the season. it takes large numbers of aphids to damage crops by direct feeding. different aphid species transmit different viruses to particular crop types; species identification is important because management strategies can vary. integrated management practices that aim to control aphid populations early in the season are important to minimising virus spread. [18]

7.4.6 Thresholds for control

When determining economic thresholds for aphids, it is critical to consider several other factors before making a decision. Most importantly, the current growing conditions and moisture availability should be assessed. Crops that are not moisture stressed have a greater ability to compensate for aphid damage and will generally be able to tolerate far higher infestations than moisture stressed plants before a yield loss occurs.

Recommended control thresholds are more than 15 aphids per tiller on 50% of tillers if the expected yield will exceed 3 t/ha.

Thresholds for managing aphids to prevent the incursion of aphid-vectored virus have not been established and will be much lower than any threshold to prevent yield loss via direct feeding. [19]

Aphid populations can decline rapidly, which may make control unnecessary. In many years, aphid populations will not reach threshold levels.

17 DAFQ (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

18 GRDC. (2010). Aphids and viruses in pulse crops Fact sheet – western and southern regions. https://grdc.com.au/uploads/documents/GRDC_FS_AphidsAndViruses.pdf

19 P Umina, S Hangartner (2015) Oat aphid. Cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

7.4.7 Management of aphids

Though aphid numbers are rarely high enough to warrant control, it is important to know the critical periods for aphid management (Figure 8).

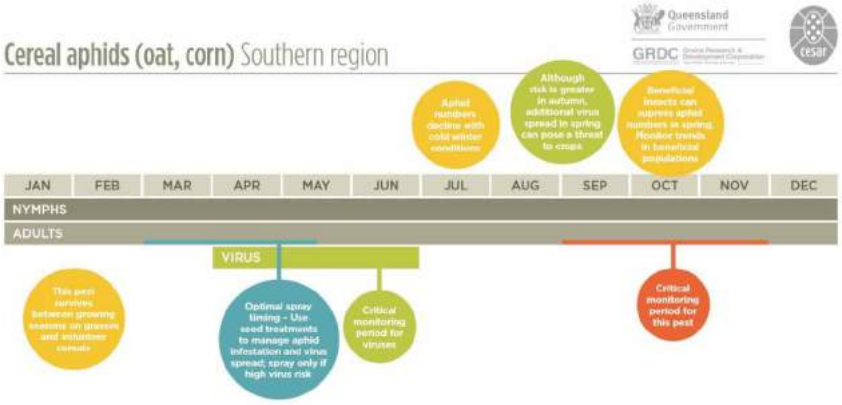


Figure 8: *Lifecycles, critical monitoring and management periods for cereal aphids in the southern region of Australia.*

Source: cesar and QDAFF

Biological control

There are many effective natural enemies of aphids. Hoverfly larvae, lacewings, ladybird beetles and damsel bugs are known predators that can suppress populations. Aphid parasitic wasps lay eggs inside bodies of aphids and evidence of parasitism is seen as bronze-coloured enlarged aphid "mummies". As mummies develop at the latter stages of wasp development inside the aphid host, it is likely that many more aphids have been parasitized than indicated by the proportion of mummies. Naturally occurring aphid fungal diseases (*Pandora neoaphidis* and *Conidiobolyus obscurus*) can also suppress aphid populations.

Cultural control to manage MYDV threat from aphids

Sowing resistant cereal varieties is the most effective method of reducing losses to BYDV. See crop variety guides for susceptibility ratings.

Control summer and autumn weeds in and around crops, particularly volunteer cereals and grasses, to reduce the availability of alternate hosts between growing seasons.

Where feasible, sow into standing stubble and use a high sowing rate to achieve a dense crop canopy, which will assist in deterring aphid landings.

Delayed sowing avoids the autumn peak of cereal aphid activity and reduces the incidence of BYDV. However, delaying sowing generally reduces yields, and this loss must be balanced against the benefit of lower virus incidences.

Chemical control

The use of insecticide seed treatments can delay aphid colonisation and reduce early infestation, aphid feeding and the spread of cereal viruses.

There are several insecticides registered against corn aphids in various crops including cereals. A border spray in autumn/early winter, when aphids begin to move into crops, may provide sufficient control without the need to spray the entire paddock.

Avoid the use of broad-spectrum "insurance" sprays, and apply insecticides only after monitoring and distinguishing between aphid species. Consider the populations of beneficial insects before making a decision to spray, particularly in spring when these

natural enemies can play a very important role in suppressing aphid populations if left untouched. [20]

Monitoring

Monitor all crop stages from seedling stage onwards. Look on leaf sheaths, stems, within whorls and heads, and record the number of large and small aphids (adults and juveniles), beneficials (including parasitised mummies), and the impact of the infestation on the crop.

Stem elongation to late flowering is the most vulnerable stage. Frequent monitoring is required to detect rapid increases of aphid populations.

Check regularly—at least five points in the field and sample 20 plants at each point. Populations may be patchy—densities at crop edges may not be representative of the whole field.

Average number of aphids per stem/tiller samples gives a useful measurement of their density. Repeated sampling will provide information on whether the population is increasing (lots of juveniles relative to adults), stable, or declining (lots of adults and winged adults). [21]

7.5 Armyworm

Armyworms are caterpillar pests of grass pastures and cereal crops. They are the only caterpillars that growers are likely to encounter in cereal crops, although occasionally native budworm will attack grain when underlying weed hosts dry out. Armyworms mostly feed on leaves, but under certain circumstances will feed on the seed stem, resulting in head loss. The change in feeding habit is caused by depletion of green leaf material or crowding. In the unusual event of extreme food depletion and crowding, they will "march" out of crops and pastures in search of food, which gives them the name "armyworm".

There are three common species of armyworm found in southern Australia:

- Common armyworm (*Mythimna convecta*)
- Southern armyworm (*Persectania ewingii*)
- Inland armyworm (*Persectania dyscrita*)

These are native pests. Common armyworm (*Leucania convecta*) is found in all states of Australia and potentially will invade all major broadacre-cropping regions year round, but particularly in spring and summer. The *Persectania* species are more typically found in southern regions of Australian autumn and winter, but their activity can sometimes extend into spring.

Caterpillars of the three species are similar in appearance. They grow from about 2–40 mm in length. They have three prominent white or cream stripes running down the back and sides of their bodies. These are most obvious where they start on the thoracic segment ("collar") immediately behind the head, and become particularly apparent in larvae that are >10 mm. They have no obvious hairs, are smooth to touch and curl up when disturbed. Armyworms have four abdominal prolegs (Figure 9).

Mature caterpillars are 30–40 mm long. For an accurate identification, they must be reared through to the adult (moth) stage.

Armyworms can be distinguished from other caterpillar pests that may be found in the same place by three pale stripes running the length of the body; these stay constant no matter the variation in the colour of the body.

Other species of caterpillar that may be confused with armyworms include:

- Loopers (tobacco looper or brown pasture looper) walk with a distinct looping action and have one or two pairs of abdominal prolegs. Armyworms have four pairs, and when >10 mm do not walk with a looping action.

20 P Umina, S Hangartner (2015) Oat aphid. Cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

21 IPM Guidelines (2016) Aphids in winter cereals, http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-winter-cereals/

- Budworm larvae have prominent but sparse hairs and bumps on their skin; anthelid larvae are covered in hairs. Armyworms are smooth bodied with no obvious hairs.
- Cabbage moth larvae wriggle vigorously when disturbed. Armyworms curl up into a tight "C".
- Cutworm (brown or common cutworm) larvae have no obvious stripes or markings and are uniformly brown, pink or black.

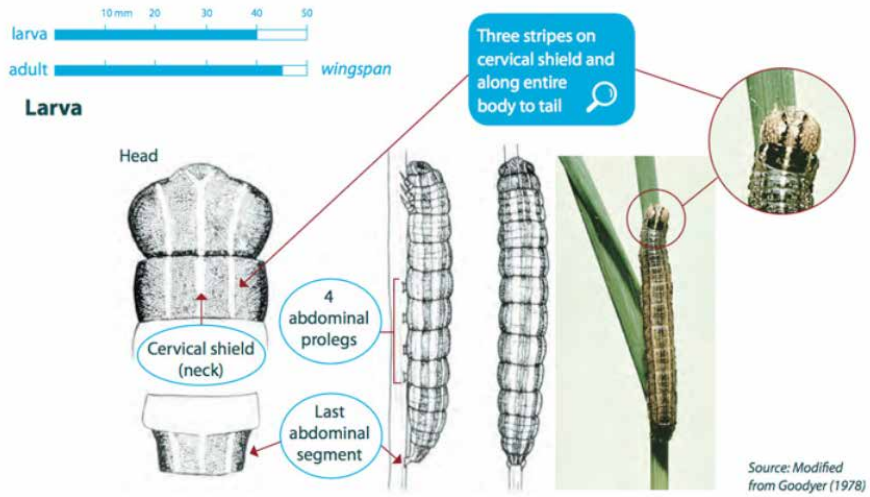


Figure 9: *Distinguishing characteristics of Armyworm larvae.*

Source: cesar

Adults

Moths are often seen flying on warm, humid nights. They are medium-sized, with a wingspan of 30–40 mm. Each species has a characteristic colour and wing markings.

Southern armyworm: grey-brown to red-brown forewings with white zigzag markings on the outer tips and a pointed white "dagger" in the middle of the forewing. The hind wings are dark grey (Figure 10).

Inland armyworm: similar to the southern armyworm except that the white "dagger" in the centre of the forewing is divided into two discrete light ellipses which almost touch. The hind wings are pale grey.

Common armyworm: the forewings are dull yellow to red-brown, speckled with tiny black dots and a small white dot near the centre.

Pupae of all three species are about 20 mm long, shiny brown and are found under clods or within cracks in the soil. [22]

22 G McDonald (1995) Armyworms, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms

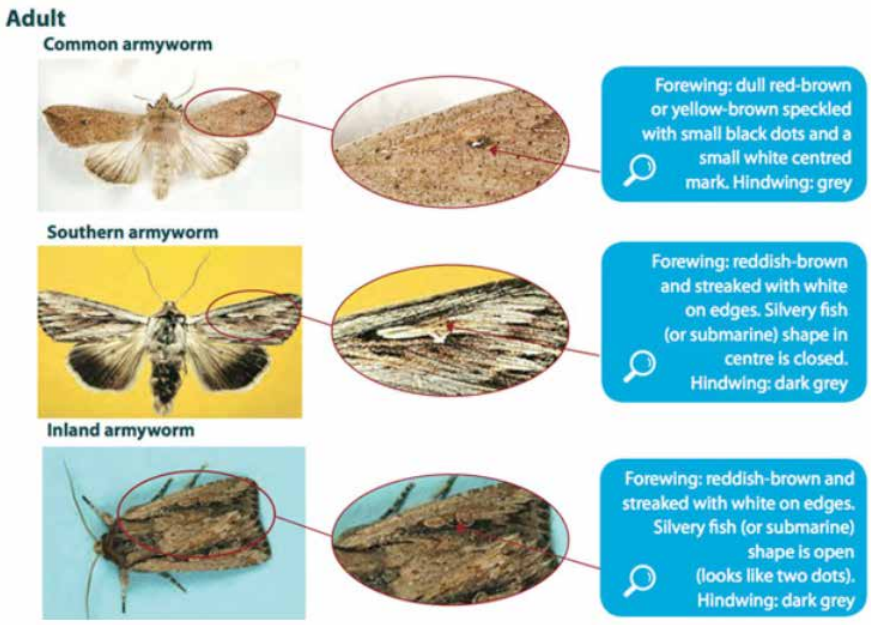


Figure 10: *Distinguishing characteristics of the three Armyworm adult moth species.*

Source: cesar

7.5.1 Damage caused by armyworms

- Prefer lush growth that provides good cover and protection.
- Feed on leaf tissue—leaf margins have tattered/chewed/scalloped appearance; in extreme cases whole leaves may be severed at the stem.
- Caterpillars produce green/straw coloured droppings (size of match head). These are visible between the rows.
- Bare patches adjacent to barley fields or damage to weeds may indicate armyworm presence before it is evident in crops. [23]

The young larvae feed initially from the leaf surface of pasture grasses and cereals. As the winter and spring progress and the larvae grow, they chew “scallop” marks from the leaf edges. This becomes increasingly evident by mid to late winter. By the end of winter or early spring, the larvae are reaching full growth and maximum food consumption. It is this stage that farmers most frequently notice as complete leaves and tillers may be consumed or removed from the plant.

Damaging infestations or outbreaks occur in three situations:

In winter when young tillering cereals are attacked and can be completely defoliated. The caterpillars may come from:

- the standing stubble from the previous year's cereal crop, in which the eggs are laid; or
- neighbouring pastures that dry out, resulting in the resident armyworms being forced to march into the crop.

In spring / early summer when crops commence ripening and seed heads may be lopped.

In early summer when grass pastures are cut for hay, particularly in Gippsland.

Leaves of cereal plants or grasses appear chewed ("leaf scalloping") along the edges. The most damage, however, is caused in ripening crops when the foliage dries off. The armyworms then begin to eat any green areas remaining. In cereals, the last section of the stem to dry out is usually just below the seed head. Armyworms, particularly the older ones, that chew at this vulnerable spot cause lopping of the

23 IPM Guidelines (2016) Armyworm, http://ipmguidelinesforgrains.com.au/pests/armyworm/

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Armyworms—Agriculture Victoria.

heads and can devastate a crop nearing maturity in one or two nights. Generally, the larger the armyworm, the greater the damage. In wheat and barley, whole heads are severed, while in oats individual grains are bitten off below the glumes.

The crops affected include all Gramineae crops including cereals, grassy pastures, corn and maize.

7.5.2 Thresholds for control

Economic threshold estimated at a minimum of 10 grubs/m^2 (higher than barley as heads are rarely lopped). [24]

For winter outbreaks (during tillering), economic thresholds of 8–10 larvae/m^2 provide a guide for spray decisions. For spring outbreaks (during crop ripening) spraying is recommended when the density of larvae exceeds 1–3 larvae/m^2 although this figure must be interpreted in the light of:

- timing of harvest;
- green matter available in the crop;
- expected return on the crop; and
- larval development stage (if most are greater than 35–40 mm or pupating, it may not be worth spraying). [25]

7.5.3 Managing armyworms

Sampling and detection

Signs of the presence of armyworms include:

- Chewing/leaf scalloping along the leaf margins.
- Caterpillar excreta or "frass" which collects on leaves or at the base of the plant. These appear as green or yellow cylindrical pellets 1–2 mm long.
- Cereal heads or oat grains on the ground. Oat grains may be attached to a small piece of stalk (1–2 mm), whereas wind removed grains are not. Barley heads may be severed completely, or hang from the plant by a small piece of stalk.

Early detection is essential, particularly when cereals and pasture seed or hay crops are at the late ripening stage. Although accurate estimates of caterpillar densities require considerable effort, the cost saving is worthwhile.

Sampling can be achieved by using a sweep-net/bucket, or visually ground or crop searching for either caterpillars or damage symptoms.

The sweep-net/bucket method provides a rapid and approximate estimate of infestation size. The net or bucket should be swept across the crop in 180° arcs several times—preferably 100 times—at different sites within the crop to give an indication of density and spread. Armyworms are most active at night, so sweeping will be most effective at dusk. Average catches of more than 5—10 per 100 sweeps suggest that further searches on the ground are warranted to determine approximate densities.

When ground sampling, it is necessary to do at least ten "spot checks" in the crop, counting the number of caterpillars within a square metre.

Most farmers fail to detect armyworms until the larvae are almost fully grown, and 10–20% damage may result. The earlier the detection, the less the damage. The young larvae (up to 8 mm) cause very little damage, and are more difficult to find. The critical time to look for armyworms is the last 3–4 weeks before harvest. [26]

It is important to know the critical periods for control in armyworms (Figure 11).

24 IPM Guidelines (2016) Armyworm, http://ipmguidelinesforgrains.com.au/pests/armyworm/

25 G McDonald (1995) Armyworms, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms

26 G McDonald (1995) Armyworms, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms

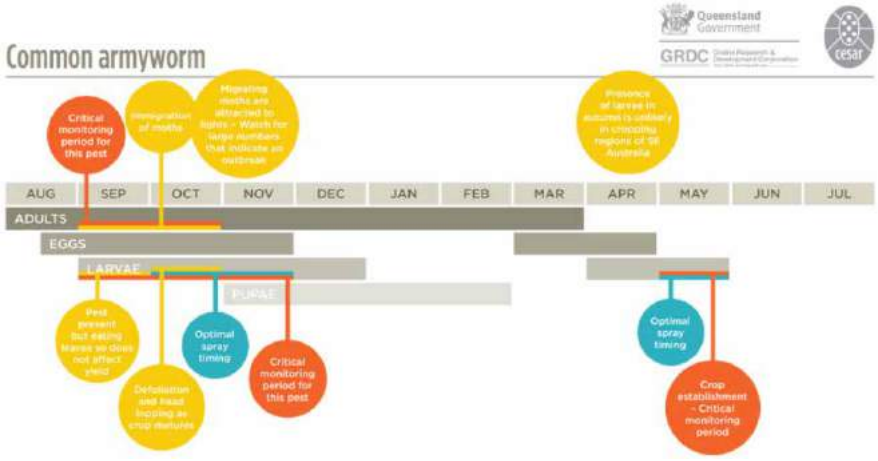


Figure 11: *Critical periods for control in armyworms.*

Source: cesar

Biological control

Around 20 species of predator and parasitoids have been recorded attacking armyworm. The most frequently observed predators are predatory shield bugs, ladybeetles, carabid beetles, lacewings and common brown earwigs. Parasitoids include tachnid flies and a number of wasp species (e.g. *Netelia*, *Lissopimpla*, *Campoletis*). Viral and fungal diseases are recorded as causing mortality of armyworm. Such outbreaks are more common at high armyworm densities.

Cultural control

Control weeds to remove alternative hosts. Armyworm often feed on ryegrass before moving into cereal crops.

Standing stubble from previous crops, dead leaves on crops and grassy weeds are suitable sites for female armyworm to lay eggs.

Larvae can move into cereals if adjacent pastures are chemically fallowed, spray topped or cultivated in spring. Monitor for at least a week post treatment. Damage is generally confined to crop margins.

Chemical control

Effectiveness requires good coverage to get contact with the caterpillars. Control is more difficult in high-yielding crops with thick canopies where larvae are resting under leaf litter at the base of plants.

Armyworms are active at night—spray late afternoon or early evening to maximum likelihood of contact.

Be aware of withholding periods when chemical control is used close to harvest. [27]

7.6 Cutworm (*Agrotis* spp.)

Cutworms are caterpillars of several species of night-flying moths, one of which is the well-known bogong moth. The mature grubs are plump, smooth caterpillars (Photo 7). The caterpillars are called cutworms because they cut down young plants as they feed on stems at or below the soil surface. They are most damaging when caterpillars transfer from summer and autumn weeds onto newly emerged seedlings. Natural predators and early control of summer and autumn weeds will help reduce larval survival prior to crop emergence. If required, cutworms can be controlled with insecticides; spot spraying may provide adequate control.

27 IPM Guidelines (2016) Armyworm, http://ipmguidelinesforgrains.com.au/pests/armyworm/

Photo 7: *Cutworm larva in typical curled position when disturbed.*

Source: cesar

Cutworms are sporadic pests that are widely distributed in SA, Tasmania, Victoria, WA, NSW and Queensland. Winter generation moths emerge in late spring and summer. Eggs are laid onto summer and autumn weeds, where larvae can then emerge onto newly sown crops.

There are several species of pest cutworms that are all similar in appearance. Generally larvae of all species grow to about 40–50 mm long and are relatively hairless, with a distinctly plump, greasy appearance and dark head (Figure 12).

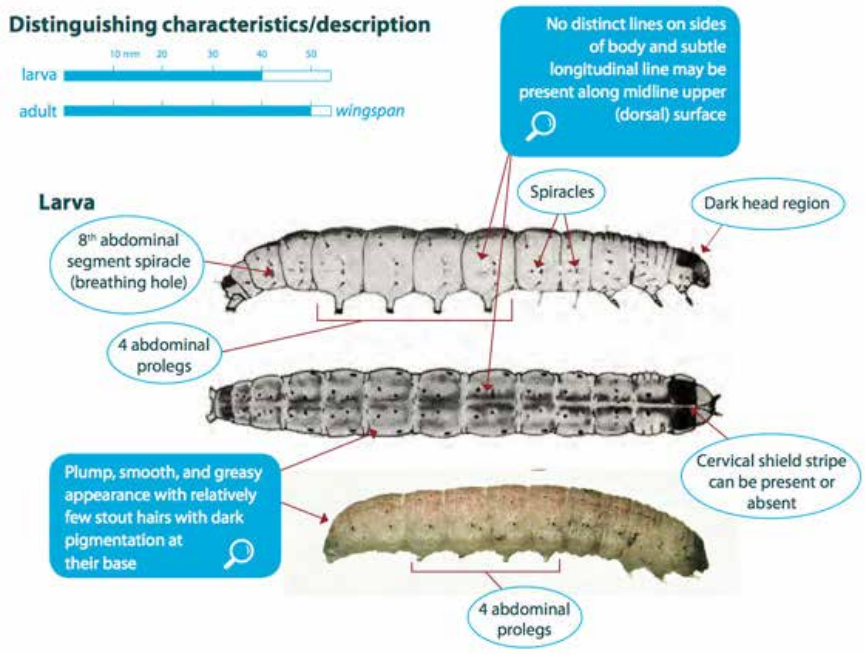


Figure 12: *Distinguishing characteristics of the cutworm.*

Source: Bellati et al. (2012) in cesar

Moths of the common cutworm (sometimes referred to as Bogong moths) have dark brown or grey-black forewings with dark arrow markings on either wing above a dark streak broken by two lighter coloured dots (Figure 13). Moths of the pink cutworm have grey-brown forewings with darker markings and streaks and a large inner light mark and darker outer mark. Moths of the black cutworm have brown or grey-black forewings with a dark arrow-mark streak broken by two dark ring-shaped dots.

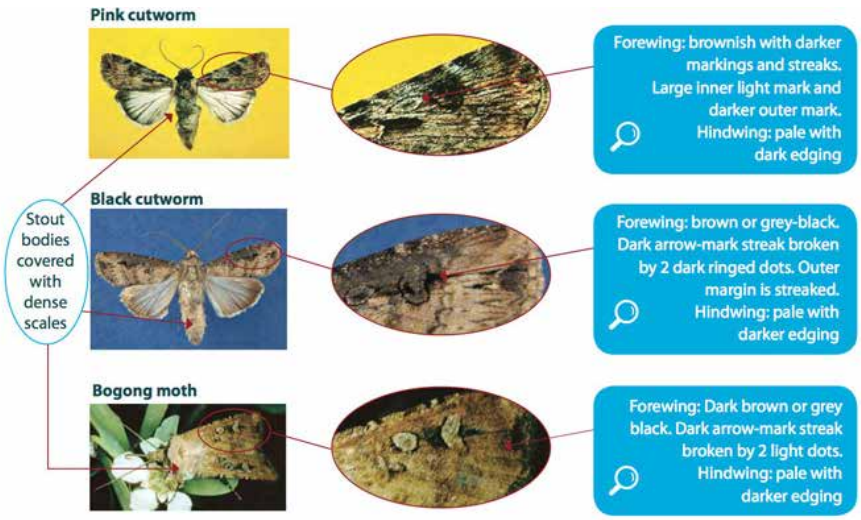


Figure 13: *Distinguishing characteristics of the adult forms of the pink, black and common cutworm.*

Source: Bellati et al. (2012) in cesar

7.6.1 Damage caused by cutworms

Larvae feed at ground level, chewing through leaves and stems. Stems are often cut off at the base, hence the name "cutworm". Winter crops are most susceptible in autumn and winter, although damage can occur throughout the year, especially in irrigated crops. Damage mostly occurs at night when larvae are active. When

numbers of larvae are high, crops can be severely thinned (Figure 8). Smaller larvae can cause similar damage to lucerne flea when they feed on leaf surface tissue. Young plants are favoured and are more adversely affected than older plants.

Occasionally, another undescribed genus of caterpillars marked with a herringbone pattern on their abdomen inflict cutworm-like damage on emerging crops.

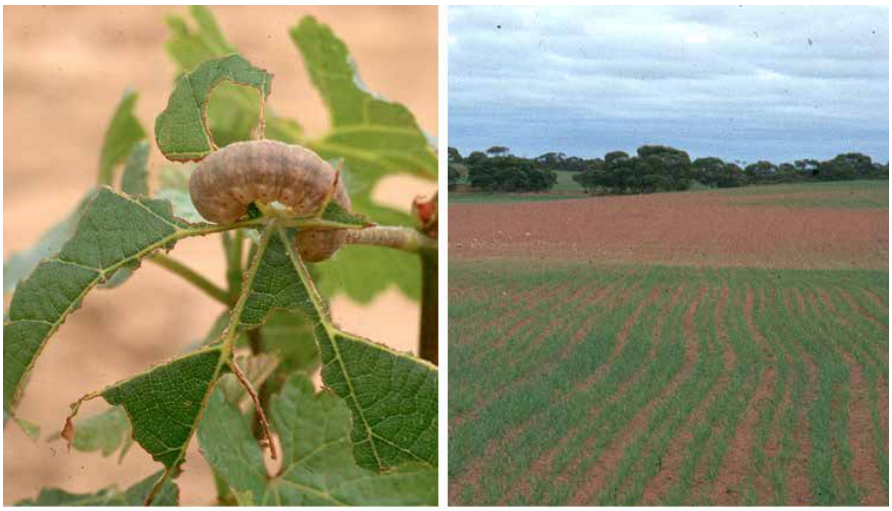


Photo 8: *Pink cutworm damage to the plant and paddock.*

Source: cesar

7.6.2 Thresholds for control

Treatment of cereals and canola is warranted if there are two or more larvae per 0.5 m of row.

7.6.3 Managing cutworm

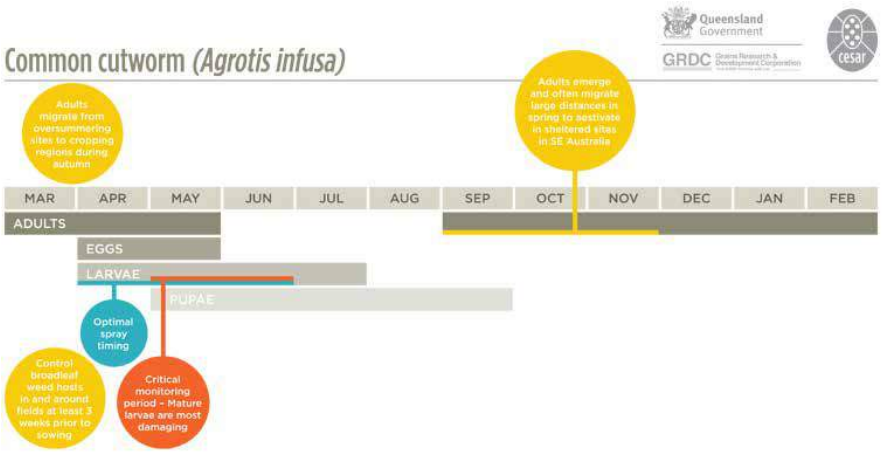


Figure 14: *Critical periods for controlling cutworm.*

Source: cesar

Biological

Naturally occurring insect fungal diseases that affect cutworms can reduce populations. Wasp and fly parasitoids, including the orange caterpillar parasite (*Netelia producta*), the two-toned caterpillar parasite (*Heteropelma scaposum*) and the orchid dupe (*Lissopimpla excelsa*) can suppress cutworm populations. Spiders are generalist predators so will also prey upon cutworms.

Cultural

As autumn cutworm populations may be initiated on crop weeds or volunteers in and around the crop, removal of this green bridge three to four weeks before crop emergence will remove food for the young cutworms.

If required, cutworms can be easily controlled with insecticides, and spot spraying may provide adequate control. Spraying in the evening is likely to be most effective.

Chemical

If required, cutworms can be easily controlled with insecticides. Several chemicals are registered for controlling cutworms, depending on the state and crop of registration. Spot spraying often provides adequate control in situations where cutworms are confined to specific regions within paddocks. Spraying in the evening is likely to be more effective as larvae are emerging to feed and insecticide degradation is minimised. [28]

7.7 Mites

7.7.1 Redlegged earth mite

The redlegged earth mite (*Halotydeus destructor*) (RLEM) is a major pest of pastures, crops and vegetables in regions of Australia with cool wet winters and hot dry summers, costing the Australian grains industry approximately $44.7 million per year. [29] The RLEM was accidentally introduced into Australia from the Cape region of South Africa in the early 1900s. These mites are commonly controlled using pesticides, however, non-chemical options are becoming increasingly important due to evidence of resistance and concern about long-term sustainability.

The RLEM is widespread throughout most agricultural regions of southern Australia. They are found in southern NSW, on the east coast of Tasmania, the south-east of SA, the south-west of WA and throughout Victoria (Figure 15). Genetic studies have found high levels of gene flow and migration within Australia. Although individual adult RLEM only move short distances between plants in winter, recent surveys have shown an expansion of the range of RLEM in Australia over the last 30 years. Long range dispersal is thought to occur via the movement of eggs in soil adhering to livestock and farm machinery or through the transportation of plant material. Movement also occurs during summer when over-summering eggs are transported by wind.

28 S Hangartner, G McDonald, P Umina (2015) Cutworm, http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cutworm

29 GRDC (2013) Ground cover supplement—emerging issues with diseases, weeds and pests.

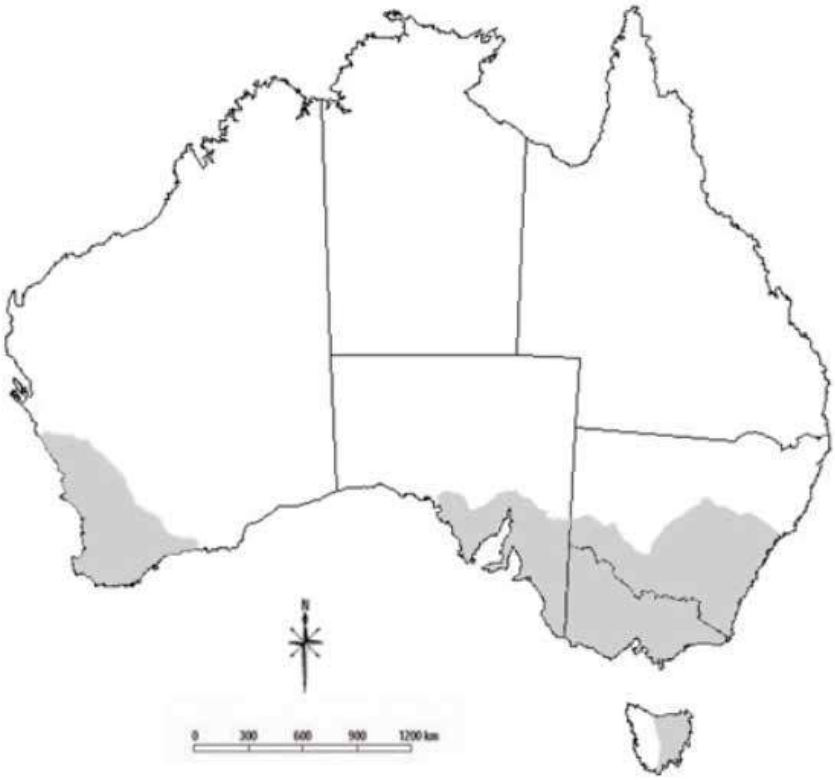


Figure 15: *The known distribution of redlegged earth mites in Australia.*

Source: cesar

Adult RLEM are 1 mm in length and 0.6 mm wide (the size of a pin head) with 8 red-orange legs and a completely black velvety body (Figure 16). Newly hatched mites are pinkish-orange with 6 legs, are only 0.2 mm long and are not generally visible to the untrained eye. The larval stage is followed by three nymphal stages in which the mites have 8 legs and resemble the adult mite, but are smaller and sexually undeveloped.

Other mite pests, in particular blue oat mites and the balaustium mite, are sometimes confused with RLEM in the field. Blue oat mites can be distinguished from RLEM by an oval orange/reddish mark on their back, while the balaustium mite has short hairs covering its body and can grow to twice the adult size of RLEM. Unlike other species that tend to feed singularly, RLEM generally feed in large groups of up to 30 individuals.

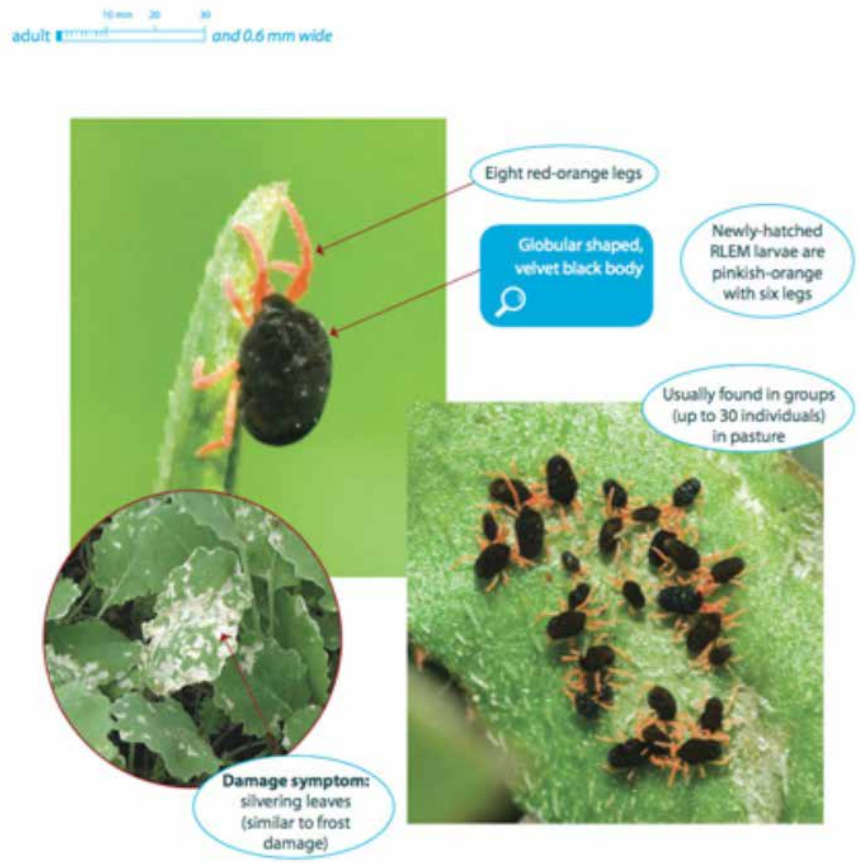


Figure 16: *Distinguishing characteristics of RLEM.*

Source: Bellati *et al.* (2012) in cesar

Damage caused by RLEM

Typical mite damage appears as “silvering” or “whitening” of the attacked foliage. Mites use adapted mouthparts to lacerate the leaf tissue of plants and suck up the discharged sap. The resulting cell and cuticle damage promotes desiccation, retards photosynthesis and produces the characteristic silvering that is often mistaken as frost damage. RLEM are most damaging to newly establishing pastures and emerging crops, greatly reducing seedling survival and development. In severe cases, entire crops may need re-sowing following RLEM attack.

RLEM hosts include pasture legumes, subterranean and other clovers, medics and lucerne. They are particularly damaging to seedlings of all legumes, oilseeds and lupins when in high numbers. They feed on ryegrass and young cereal crops, especially oats. RLEM also feed on a range of weed species including Patersons' curse, skeleton weed, variegated thistle, ox-tongue, smooth cats' ear and capeweed.

RLEM feeding reduces the productivity of established plants and has been found to be directly responsible for reduction in pasture palatability to livestock.

Managing RLEM

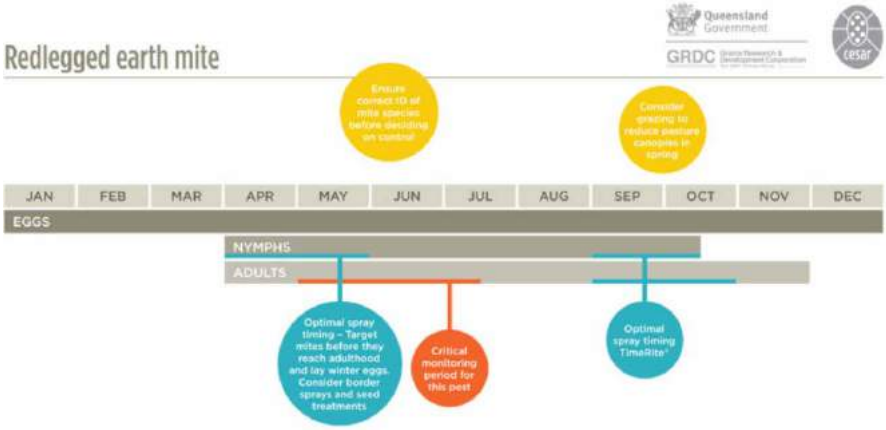


Figure 17: *Critical periods for managing RLEM.*

Source: cesar

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 three to five weeks after sowing. Mites are best detected feeding on the leaves in the morning or on overcast days. In the warmer part of the day RLEM tend to gather at the base of plants, sheltering in leaf sheaths and under debris. They will crawl into cracks in the ground to avoid heat and cold. When disturbed during feeding they will drop to the ground and seek shelter.

RLEM compete with other pasture pests, such as blue oat mites, for food and resources. Competition within and between mite species has been demonstrated in pastures and on a variety of crop types. This means control strategies that only target RLEM may not entirely remove pest pressure because other pests can fill the gap. This can be particularly evident after chemical applications, which are generally more effective against RLEM than other mite pests.

Chemical control

Chemicals are the most commonly used control option against earth mites. While a number of chemicals are registered for control of active RLEM in pastures and crops, there are no currently registered pesticides that are effective against RLEM eggs.

Autumn sprays:

Controlling first generation mites before they have a chance to lay eggs is the only effective way to avoid the need for a second spray. Hence, pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, before adults begin to lay eggs. Timing of chemical application is critical.

Pesticides with persistent residual activity can be used as bare earth treatments, either pre-sowing or at sowing to kill emerging mites. This will protect seedlings, which are most vulnerable to damage.

Foliage sprays are applied once the crop has emerged and are generally an effective method of control.

Systemic pesticides are often applied as seed dressings. Seed dressings act by maintaining the pesticide at toxic levels within the growing plant, which then affects mites as they feed. This strategy aims to minimise damage to plants during the sensitive establishment phase. However, if mite numbers are high, plants may suffer significant damage before the pesticide has much effect.

Spring sprays:

Research has shown that one accurately timed spring spray of an appropriate chemical can significantly reduce populations of RLEM the following autumn. This

approach works by killing mites before they start producing diapause eggs in mid-late spring. The optimum date can be predicted using climatic variables and tools such as TIMERITE® can help farmers identify the optimum date for spraying. Spring RLEM sprays will generally not be effective against other pest mites.

Repeated successive use of the "spring spray" technique is not recommended as this could lead to populations evolving resistance to the strategy. To prevent the development of resistance, the selective rotation of products with different Modes of Action is advised.

Biological control

There is evidence of natural RLEM populations showing resistance to some chemicals; therefore, alternative management strategies are needed to complement current control methods.

At least 19 predators and one pathogen are known to attack earth mites in eastern Australia. The most important predators of RLEM appear to be other mites, although small beetles, spiders and ants also play a role in reducing populations. A predatory mite (*Anystis wallacei*) has been introduced as a means of biological control; however, it has slow dispersal and establishment rates. Although locally successful, the benefits of this mite are yet to be demonstrated.

Preserving natural enemies may prevent RLEM population explosions in established pastures, but this is often difficult to achieve. This is mainly because the pesticides generally used to control RLEM are broad-spectrum and kill beneficial species as well as the pests. The chemical impact on predator species can be minimised by choosing a spray that has least impact and by reducing the number of chemical applications. Although there are few registered alternatives for RLEM, there are groups that have low-moderate impacts on many natural enemies such as cyclodienes.

Natural enemies residing in windbreaks and roadside vegetation have been demonstrated to suppress RLEM in adjacent pasture paddocks. When pesticides with residual activity are applied as border sprays to prevent mites moving into a crop or pasture, beneficial insect numbers may be inadvertently reduced, thereby protecting RLEM populations.

Cultural control

Using cultural control methods can decrease the need for chemical control. Rotating crops or pastures with non-host crops can reduce pest colonisation, reproduction and survival. For example, prior to planting a susceptible crop like, a paddock may be sown to cereals or lentils to help reduce the risk of RLEM population build up. Cultivation can also help reduce RLEM populations by significantly decreasing the number of over-summering eggs. Hot stubble burns can provide a similar effect.

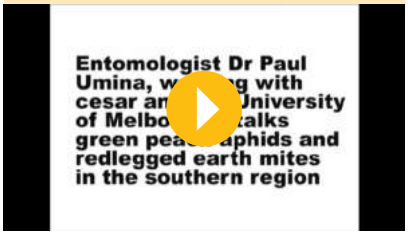
Clean fallowing and controlling weeds around crop and pasture perimeters can also act to reduce mite numbers. Control of weeds, especially thistles and capeweed, is important, as they provide important breeding sites for RLEM. Where paddocks have a history of damaging, high-density RLEM populations, it is recommended that sowing pastures with a high clover content be avoided.

Appropriate grazing management can reduce RLEM populations to below damaging thresholds, possibly because shorter pasture results in lower relative humidity, which increases mite mortality and limits food resources.

Other cultural techniques including modification of tillage practices, trap or border crops, and mixed cropping can reduce overall infestation levels to below the economic control threshold, particularly when employed in conjunction with other measures. [30]

VIDEOS

WATCH: Green peach aphid and redlegged earth mite resistance in Australia's southern cropping region.



30 P Umina (2007) Redlegged earth mite, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/?a=223443

7.7.2 Balaustium mite

The *Balaustium* mite, *Balaustium medicagoense* (Acari: Erythreidae), has recently been identified within the Australian grains industry as an emerging pest of winter crops and pasture. This mite is the only species of the genus *Balaustium* recorded in Australia and was probably introduced from South Africa, along with the redlegged earth mite (*Halotydeus destructor*), in the early 1900s. *Balaustium* mites are found throughout areas of southern Australia that have a Mediterranean-type climate, attacking a variety of agriculturally important plants.

They are sporadically found in areas with a Mediterranean climate in Victoria, NSW, SA and WA (Figure 18). They have also been found in Tasmania although their exact distribution is unclear. *Balaustium* mites are typically active from March to November, although mites can persist on green feed during summer if available.

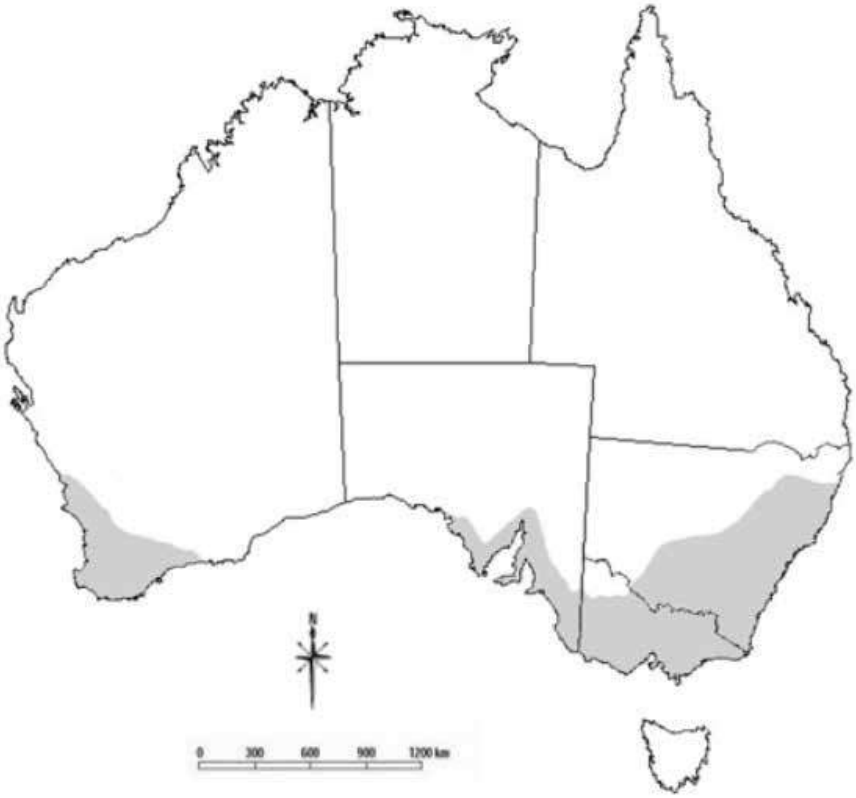


Figure 18: *The known distribution of Balaustium mites in Australia.*

Source: cesar

Balaustium mites are quite often confused with other pest mites, such as the redlegged earth mite and blue oat mites (*Penthaleus* spp.). They have a rounded dark red/brown coloured body and red legs similar to other pest mites, however they have distinct short stout hairs covering their entire body giving them a velvety appearance (Figure 19). Adults reach about 2 mm in size, which is twice the size of other earth mite species. *Balaustium* mites also have distinct pad-like structures on their front legs and move slower than redlegged earth mites and blue oat mites.

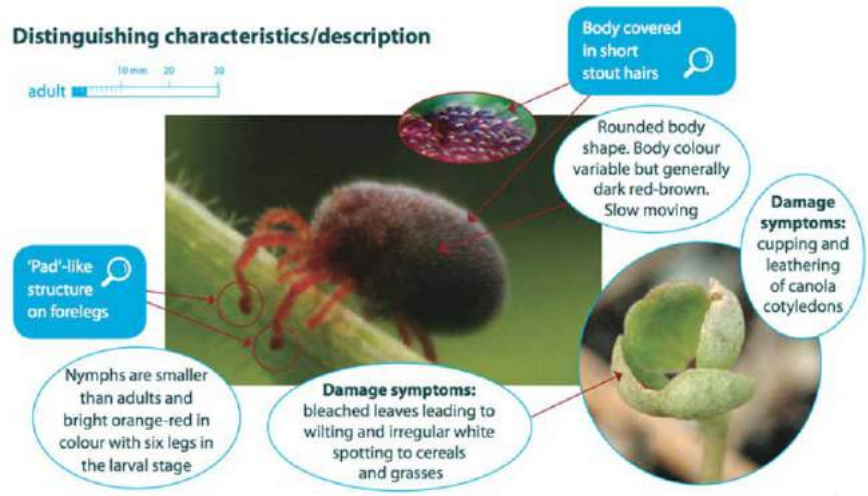


Figure 19: *Adult Balaustium mite.*

Source: Bellati et al. (2012) in cesar

Newly laid eggs of *Balaustium* mites are light maroon in colour, becoming darker prior to egg hatch. Larvae are bright orange in colour and have six pairs of legs. The larval stage is followed by a number of nymphal stages in which mites have eight legs and resemble adults, but are much smaller. [31]

Damage caused by Balaustium mite

Balaustium mites feed on plants using their adapted mouthparts to probe leaf tissue of plants and suck up sap. In most situations *Balaustium* mites cause little damage, however when numbers are high and plants are already stressed due to other environmental conditions, significant damage to crops can occur. Under high infestations, seedlings or plants can wilt and die. *Balaustium* mites typically attack leaf edges and leaf tips of plants.

There are no economic thresholds for this pest.

Management

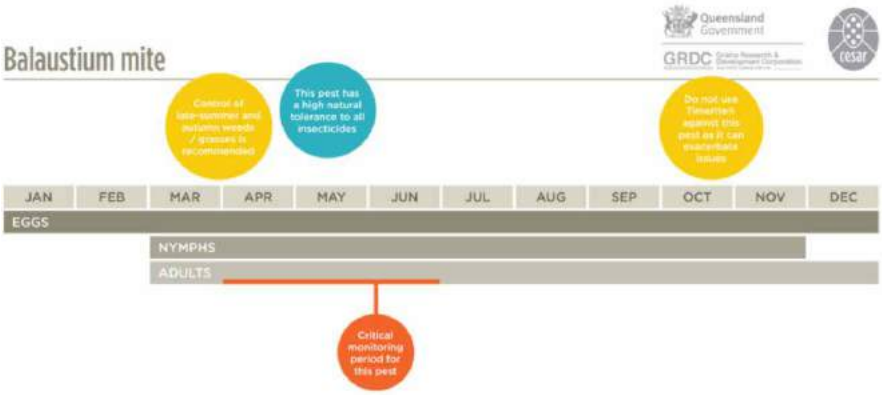


Figure 20: *Critical periods for Balaustium management.*

Source: cesar

31 D Grey (2010) Balaustium mite. Agriculture Victoria , http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/balaustium-mite

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 three to five weeks after sowing.

Crops sown into paddocks that were pasture the previous year should be regularly inspected for *Balaustium* mites. 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. *Balaustium* mites are difficult to find when conditions are cold and/or wet.

One of the most effective methods to sample mites is using a D-vac, which is based on the vacuum principle—much like a vacuum cleaner used in the home. Typically, a standard petrol powered garden blower/vacuum machine is used, such as those manufactured by Stihl® or Ryobi®. A sieve is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface.

Control

Currently no product has been registered to control *Balaustium* mite in any state or territory of Australia. The Australian Pesticides and Veterinary Medicine Authority (APVMA) maintain a database of all chemicals registered for the control of agricultural pests in Australia. Reference to the APVMA website will confirm the registration status of products for *Balaustium* mite, or consult chemical resellers or a local chemical standards officer.

Ensure the relevant Maximum Residue Limits (MRLs) for the chemical in the end market is met, be it domestic or export.

Chemical users must read and understand all sections of chemical labels prior to use.

There have been no biological control agents (predators or parasites) identified in Australia that are effective in controlling *Balaustium* mites. Alternative methods such as cultural control can be effective at controlling this mite. Early control of summer weeds, within and around paddocks, especially capeweed and grasses, can help prevent mite outbreaks. Rotating crops or pastures with non-host crops can also reduce pest colonisation, reproduction and survival. For example, prior to planting a susceptible crop like cereals, a paddock could be sown to a broadleaf plant that *Balaustium* mites have not been reported to attack, such as vetch. [32]

7.7.3 Blue oat mite

Blue oat mites (BOM) (*Penthaleus* spp.) are species of earth mites, which are major agricultural pests of southern Australia and other parts of the world, attacking various pasture, vegetable and crop plants. BOM were introduced from Europe and first recorded in NSW in 1921. Management of these mites in Australia has been complicated by the recent discovery of three distinct species of BOM, whereas prior research had assumed just a single species.

Blue oat mites are important crop and pasture pests in southern Australia. They are commonly found in Mediterranean climates of Victoria, NSW, SA, WA and eastern Tasmania (Figure 21). There are three main species of BOM: *Penthaleus major*, *Penthaleus falcatus* and *Penthaleus tectus*. These species differ in their distributions.

32 D Grey (2010) Balaustium mite. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/balaustium-mite

Figure 21: *The known distribution of blue oat mites in Australia.*

Source: cesar

Adult BOM are 1 mm in length and approximately 0.7–0.8 mm wide, with eight red-orange legs. They have a blue-black coloured body with a characteristic red mark on their back (Figure 22). Larvae are approximately 0.3 mm long, are oval in shape and have three pairs of legs. On hatching, BOM are pink-orange in colour, soon becoming brownish and then green.

Figure 22: *Distinguishing characteristics of Blue oat mite.*

Source: Bellati et al. (2012) in cesar

BOM are often misidentified as redlegged earth mites (RLEM) in the field, which has meant that the damage caused by BOM has been under-represented. Despite having a similar appearance, RLEM and BOM can be readily distinguished from each other. RLEM have a completely black coloured body and tend to feed in larger groups of up to 30 individuals. BOM have the red mark on their back and are usually found singularly or in very small groups.

Damage caused by BOM

Feeding causes silvering or white discoloration of leaves and distortion, or shrivelling in severe infestations. Affected seedlings can die at emergence with high mite populations. Unlike redlegged earth mites, blue oat mites typically feed singularly or in very small groups.

Mites use adapted mouthparts to lacerate the leaf tissue of plants and suck up the discharged sap. Resulting cell and cuticle destruction promotes desiccation, retards photosynthesis and produces the characteristic silvering that is often mistaken as frost damage (Photo 9). BOM are most damaging to newly establishing pastures and emerging crops, greatly reducing seedling survival and retarding development.

Photo 9: *Typical Blue oat mite damage to leaf.*

Source: AgVic

Young mites prefer to feed on the sheath leaves or tender shoots near the soil surface, while adults feed on more mature plant tissues. BOM feeding reduces the productivity of established plants and is directly responsible for reductions in pasture palatability to livestock. Even in established pastures, damage from large infestations may significantly affect productivity.

The impact of mite damage is increased when plants are under stress from adverse conditions such as prolonged dry weather or waterlogged soils. Ideal growing conditions for seedlings enable plants to tolerate higher numbers of mites.

Managing BOM

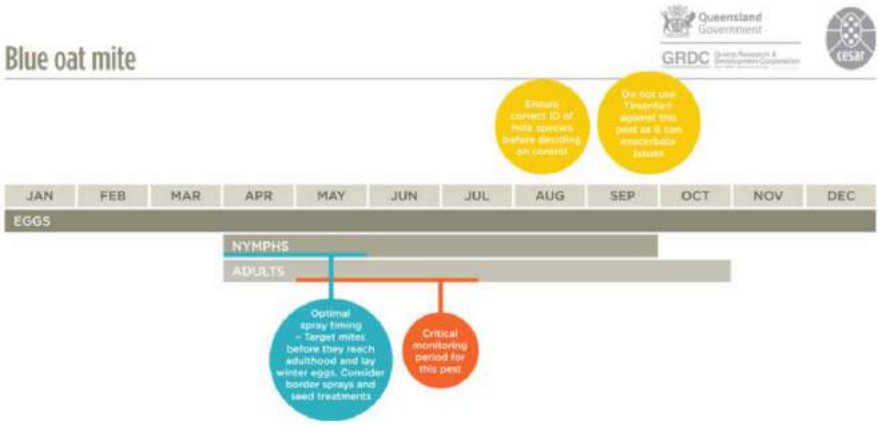


Figure 23: *Critical time periods for managing BOM.*

Source: cesar

Chemical control

Chemicals are the most common method of control against earth mites. Unfortunately, all currently registered pesticides are only effective against the active stages of mites; they do not kill mite eggs.

While a number of chemicals are registered in pastures and crops, differences in tolerance levels between species complicates management of BOM. *P. falcatus* has a high natural tolerance to a range of pesticides registered against earth mites in

Australia and is responsible for many control failures involving earth mites. The other BOM species have a lower level of tolerance to pesticides and are generally easier to control with chemicals in the field.

Chemical sprays are commonly applied at the time of infestation, when mites are at high levels and crops already show signs of damage. Control of first generation mites before they can lay eggs is an effective way to avoid a second spray. Hence, pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, as adults will then begin laying eggs. While spraying pesticides in spring can greatly reduce the size of RLEM populations the following autumn, this strategy will generally not be as effective for the control of BOM.

Pesticides with persistent residual effects can be used as bare-earth treatments. These treatments can be applied prior to, or at sowing to kill emerging mites and protect the plants throughout their seedling stage.

Systemic pesticides are often applied as seed dressings to maintain the pesticide at toxic levels within the plants as they grow. This can help minimise damage to plants during the sensitive establishment phase, however, if mite numbers are high, significant damage may still occur before the pesticide has much effect.

To prevent the buildup of resistant populations, spray pesticides only when necessary and rotate pesticides from chemical classes with different modes of action. To avoid developing multiple pesticide resistance, rotate chemical classes across generations rather than within a generation.

Information on the registration status, rates of application and warnings related to withholding periods, OH&S, residues and off-target effects should be obtained before making decisions on which pesticide to use. This information is available from the DEPI Chemical Standards Branch, chemical resellers, APVMA and the pesticide manufacturer. Always consult the label and MSDS before using any pesticide.

Biological and cultural control

Integrated pest management programs can complement current chemical control methods by introducing non-chemical options, such as cultural and biological control.

Although no systematic survey has been conducted, a number of predator species are known to attack earth mites in Australia. The most important predators of BOM appear to be other mites, although small beetles, spiders and ants may also play a role. The French anystis mite is an effective predator but is limited in distribution. Snout mites will also prey upon BOM, particularly in pastures. The fungal pathogen, *Neozygites acaracida*, is prevalent in BOM populations during wet winters and could be responsible for observed “population crashes”.

Preserving natural enemies when using chemicals is often difficult because the pesticides generally used are broad-spectrum and kill beneficial species as well as the pests. Impact on natural enemies can be reduced by using a pesticide that has the least impact and by minimising the number of applications. Although there are few registered alternatives for BOM control, there are groups such as the chloronicotinyls, which are used in some seed treatments that have low–moderate impacts on many natural enemies.

Cultural controls such as rotating crops or pastures with non-host crops can reduce pest colonisation, reproduction and survival, decreasing the need for chemical control. When *P. major* is the predominant species, canola and lentils are potentially useful rotation crops, while pastures containing predominantly thick-bladed grasses should be carefully monitored and rotated with other crops. In situations where *P. falcatus* is the most abundant mite species, farmers can consider rotating crops with lentils, while rotations that involve canola may be the most effective means of reducing the impact of *P. tectus*.

Many cultural control methods for BOM can also suppress other mite pests, such as RLEM. Cultivation will significantly decrease the number of over-summering eggs, while hot stubble burns can provide a similar effect. Many broad-leaved weeds

provide an alternative food source, particularly for juvenile stages. As such, clean fallowing and the control of weeds within crops and around pasture perimeters, especially of bristly ox tongue and cats ear, can help reduce BOM numbers.

Appropriate grazing management can also reduce mite populations to below damaging thresholds. This may be because shorter pasture results in lower relative humidity, which increases mite mortality and limits food resources. Grazing pastures in spring to less than 2 t/ha Feed On Offer (dry weight), can reduce mite numbers to low levels and provide some level of control the following year. [33]

7.7.4 *Bryobia* mite

There are over 100 species of *Bryobia* mite worldwide, with at least seven found in Australian cropping environments. Unlike other broadacre mite species, which are typically active from autumn to spring, *Bryobia* mites prefer the warmer months of the year. *Bryobia* mites are smaller than other commonly occurring pest mites. They attack pastures and numerous winter crops earlier in the season.

Bryobia mites (sometimes referred to as clover mites) are sporadic pests typically found in warmer months of the year, from spring through to autumn. They are unlikely to be a problem over winter, however they can persist throughout all months of the year. They are broadly distributed throughout most agricultural regions in southern Australia with a Mediterranean-type climate, including Victoria, SA, NSW and WA (Figure 24). They have also been recorded in Tasmania and Queensland.

Figure 24: *Known distribution of Bryobia mites in Australia.*

Source: cesar

There are at least seven species of *Bryobia* mites found in broadacre crops in Australia. These appear very similar. *Bryobia* mites are smaller than other commonly occurring pest mites, although they reach no more than about 0.75 mm in length as adults. They have an oval shaped, dorsally flattened body that is dark grey, pale orange or olive in colour and have eight pale red/orange legs. The front pair of legs

33 Agriculture Victoria (2007) Blue oat mite, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite

is much larger, approximately 1.5 times their body length. If seen under a microscope, they have a sparsely distributed set of broad, spade-like hairs, appearing like white flecks (Figure 25).

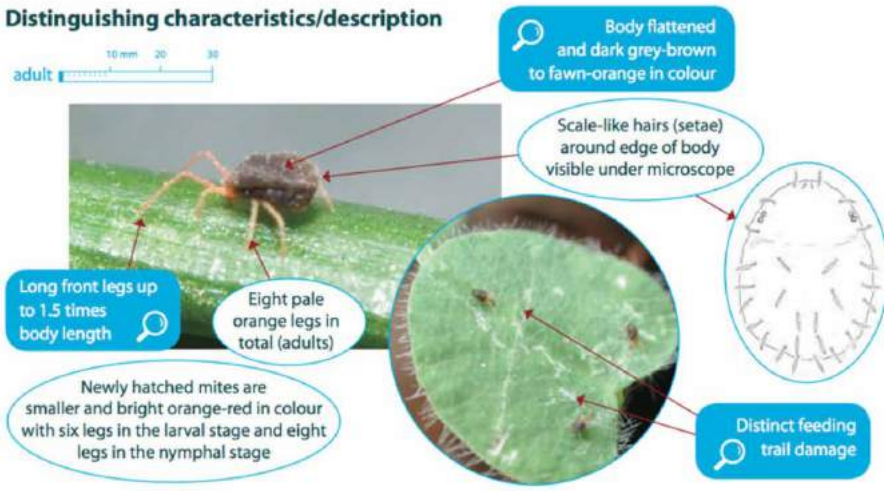


Figure 25: *Distinguishing characteristics of Bryobia mites.*

Source: Bellati et al. (2012) in cesar

Damage cause by mite

Bryobia mites tend to cause most damage in autumn when they attack newly establishing pastures and emerging crops, greatly reducing seedling survival and retarding development. They feed on the upper surfaces of leaves and cotyledons by piercing and sucking leaf material. This feeding causes distinctive trails of whitish-grey spots on leaves. Extensive feeding damage can lead to cotyledons shriveling. On grasses, Bryobia mite feeding can resemble that of redlegged earth mites.

There are no economic thresholds for control.

Managing Bryobia mites

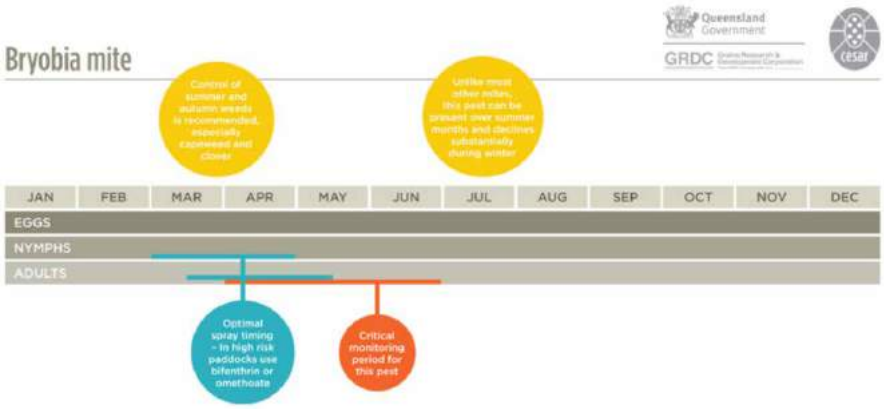


Figure 26: *Critical time periods for managing Bryobia mite.*

Source: cesar

Biological

There are currently no known biological control agents for *Bryobia* mites in Australia.

Cultural

Crops that follow pastures with a high clover content are most at risk. Avoid planting susceptible crops such as canola, lupins, vetch and lucerne into these paddocks. Early control of summer and autumn weeds within and around paddocks, especially broadleaf weeds such as capeweed and clovers, can help prevent mite outbreaks.

Chemical

Some insecticides are registered for *Bryobia* mites, however, be aware that recommended rates used against other mites might be ineffective against *Bryobia* mites. *Bryobia* mites have a natural tolerance to several chemicals. Insecticides do not kill mite eggs. Generally, organophosphate insecticides provide better control against *Bryobia* mites than synthetic pyrethroids. [34]

7.8 Lucerne flea

The lucerne flea, *Sminthurus viridis* (Collembola: Sminthuridae), is a springtail that is found in both the northern and southern hemispheres but is restricted to areas that have a Mediterranean-type climate. It is thought to have been introduced to Australia from Europe and has since become a significant agricultural pest of crops and pastures across the southern states. It is not related to the fleas, which attack animals and humans.

Lucerne fleas are common pests found in Victoria, Tasmania, SA, NSW and WA (Figure 27). Higher numbers are often found in the winter rainfall areas of southern Australia, including Tasmania, or in irrigation areas where moisture is plentiful. They are generally more problematic on loam/clay soils. Lucerne fleas are often patchily distributed within paddocks and across a region.

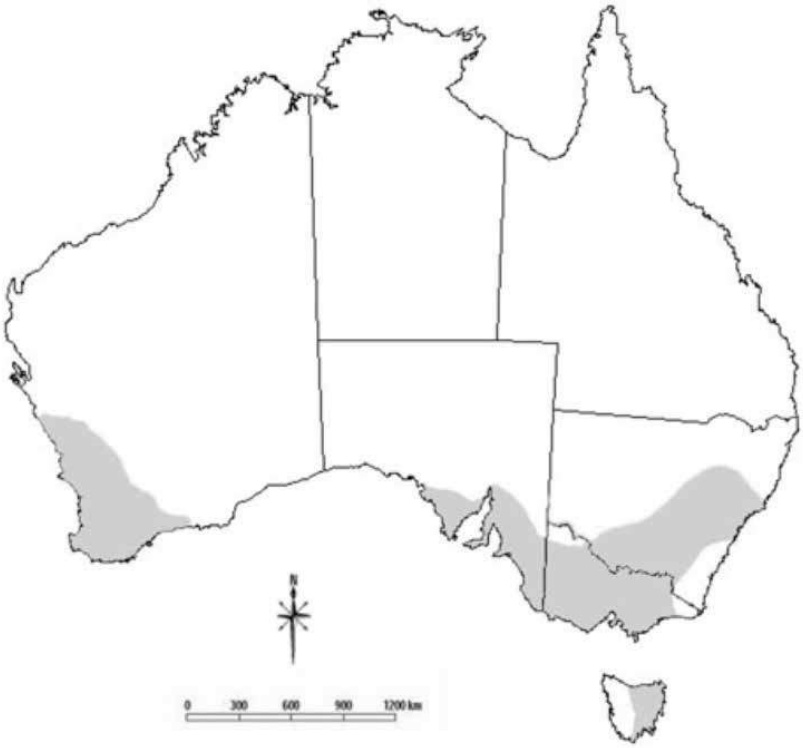


Figure 27: *The known distribution of the Lucerne flea in Australia.*

Source: cesar

34 P Umina, S Hangartner, G McDonald (2015) Bryobia mite, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Bryobia-mite

The lucerne flea is a springtail—this is a group of arthropods that have six or fewer abdominal segments and a forked tubular appendage or furcula under the abdomen. Springtails are one of the most abundant of all macroscopic insects and are frequently found in leaf litter and other decaying material, where they are primarily detritivores. Very few species, including the lucerne flea, are regarded as crop pests around the world.

The adult lucerne flea is approximately 3 mm long, light green-yellow in colour and often with mottled darker patches over the body. They are wingless and have enlarged, globular shaped abdomens (Figure 28). They are not related to true fleas. Newly hatched nymphs are pale yellow and 0.5–0.75 mm long, and as they grow they resemble adults, but are smaller.

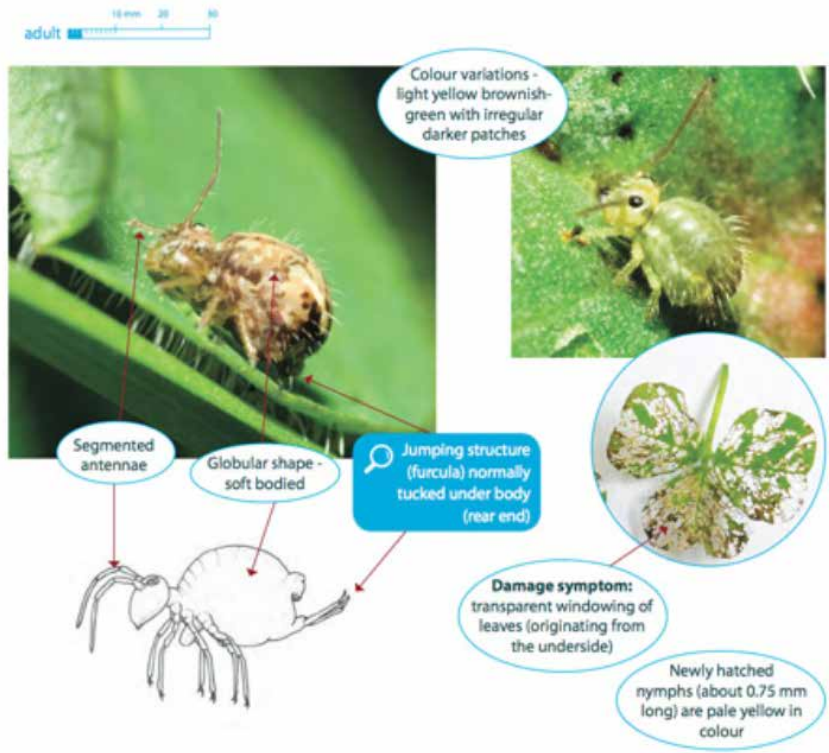


Figure 28: *Distinguishing characteristics of the Lucerne flea.*

Source: Bellati et al. (2012) in cesar

Damage caused by Lucerne flea

Although grasses and cereals are non-preferred hosts, lucerne flea can also cause damage to ryegrass, wheat and barley crops. In pastures, lucerne fleas have a preference for subterranean clover and lucerne.

Lucerne fleas move up plants from ground level, eating tissue from the underside of foliage. They consume the succulent green cells of leaves through a rasping process, avoiding the more fibrous veins and leaving behind a layer of leaf membrane. This makes the characteristic small, clean holes in leaves that can appear as numerous small “windows”. In severe infestations this damage can stunt or kill plant seedlings.

Managing Lucerne flea

Monitoring is the key to reducing the impact of lucerne flea. Crops and pastures grown in areas where lucerne flea has previously been a problem should be regularly monitored for damage from autumn through to spring. Susceptible crops and pastures should also be carefully inspected for the presence of lucerne fleas and evidence of damage.

It is important to frequently inspect winter crops, in the first three to five weeks after sowing. Crops are most susceptible to damage immediately following seedling emergence. Pastures should be monitored at least fortnightly from autumn to spring, with weekly monitoring preferred where there have been problems in previous years.

Lucerne fleas are often concentrated in localised patches or "hot spots" so it is important to have a good spread of monitoring sites within each paddock. Examine foliage for characteristic lucerne flea damage and check the soil surface where insects may be sheltering.

Some sprays require application at a particular growth stage, so it is also important to note the growth stage of the population. Spraying immature lucerne fleas before they have a chance to reproduce can effectively reduce the size of subsequent generations.

Lucerne fleas compete for food and resources with other agricultural pests such as redlegged earth mites and blue oat mites. This means control strategies that only target one species may not reduce the overall pest pressure because other pests can fill the gap. It is therefore important to assess the complex of pests before deciding on the most appropriate control strategy.

Chemical control

Lucerne fleas are commonly controlled post-emergence, usually after damage is first detected. Control is generally achieved with an organophosphate insecticide (e.g. omethoate). In areas where damage is likely, a border spray may be sufficient to stop invasion from neighbouring pastures or crops. In many cases spot spraying, rather than blanket spraying, may be all that is required.

If the damage warrants control, treat the infested area with a registered chemical approximately three weeks after lucerne fleas have been observed on a newly emerged crop. This will allow for the further hatch of over-summering eggs but will be before the lucerne fleas reach maturity and begin to lay winter eggs.

In pastures, a follow-up spray may be needed roughly four weeks after the first spray to control subsequent hatches, and to kill new insects before they lay more eggs. Grazing the pasture before spraying will help open up the canopy to ensure adequate spray coverage. The second spray is unlikely to be needed if few lucerne fleas are observed at that time.

Crops are most likely to suffer damage where they follow a weedy crop or a pasture in which lucerne flea has not been controlled. As such, lucerne flea control in the season prior to the sowing of susceptible crops is recommended.

Caution is advised when selecting an insecticide. Several chemicals registered for redlegged earth mites (i.e. synthetic pyrethroids such as cypermethrin) are known to be ineffective against lucerne flea. When both lucerne fleas and redlegged earth mites are present, it is recommended that control strategies consider both pests, and a product registered for both is used at the highest directed rate between the two to ensure effective control.

Information on the registration status, rates of application and warnings related to withholding periods, OH&S, residues and off-target effects should be obtained before making decisions on which insecticide to use. This information is available from the DPI Chemical Standards Branch, chemical resellers, APVMA and the pesticide manufacturer. Always consult the label and MSDS before using any insecticide.

Biological and cultural control

Several predatory mites, various ground beetles and spiders prey upon lucerne fleas. Snout mites (which have orange bodies and legs) are particularly effective predators of this pest (Photo 10). The pasture snout mite (*Bdellodes lapidaria*) and the spiny snout mite (*Neomulgus capillatus*), have been the focus of biological control efforts against lucerne flea.

The pasture snout mite was originally found in WA but has since been distributed to eastern Australia and there are some examples of this mite successfully reducing lucerne flea numbers. Although more rare, the spiny snout mite can also drastically reduce lucerne flea populations, particularly in autumn.

Photo 10: *Predatory adult snout mite.*

Photo: A Weeks. Source: cesar

Appropriate grazing management can reduce lucerne flea populations to below damaging thresholds. This may be because shorter pasture lowers the relative humidity, which increases insect mortality and limits food resources.

Broad-leaved weeds can provide alternative food sources, particularly for juvenile stages. Clean fallowing and the control of weeds within crops and around pasture perimeters, especially of capeweed, can therefore help reduce lucerne flea numbers.

Other cultural techniques such as cultivation, trap and border crops, and mixed cropping can help reduce overall infestation levels to below economically damaging levels, particularly when employed in conjunction with other measures. Grasses are less favourable to the lucerne flea and as such can be useful for crop borders and pastures.

In pastures, avoid clover varieties that are more susceptible to lucerne flea damage, and avoid planting susceptible crops such as canola and lucerne into paddocks with a history of lucerne flea damage. [35]

7.9 Slugs and snails

Slugs and snails are predominantly pests in the southern and western regions (Table 4). Snails are not a problem in the northern region, however damaging slug populations have been reported in seedling crops in northern NSW and southern Queensland in recent years.

Increased slug and snail activity may be due to the increase in zero/minimum till and stubble retention practices because the organic content of paddocks increases under such systems, providing an increased food source especially to young slugs and snails.

Other risk factors include prolonged wet weather, trash blankets, weedy fallows and a previous history of slugs and snails. Slugs and snails are best controlled before the crop is planted.

35 G McDonald (2008) Lucerne flea, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/lucerne-flea

Table 4: *Description of common slugs and snails.*

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Slugs				
Grey field or reticulated slug *Deroceras reticulatum*  Photo: Michael Nash, SARDI	Light grey to fawn with dark brown mottling. 35–50 mm long. Produces a white mucus.	Rasping of leaves (complete areas of crop may be missing).	Autumn to spring when conditions are moist especially when soil moisture greater than 25%.	Resident pest. Surface active, but seeks moist refuge in soil macro-pores.
Black keeled slug *Milax gagates*  Photo: Michael Nash, SARDI	Black or brown with a ridge continuing from its saddle all the way down its back to the tip of the tail. 40–60 mm long.	Rasping of leaves (complete areas of crop may be missing), and hollowed out grains.	All year round, if conditions are moist, but generally later in the season in colder regions.	Burrows so cereal/ maize crops fail to emerge/ Prefers sandy soil in high rainfall areas (>550 mm), heavier soils in low rainfall areas (<500 mm). Surface active (feeding), but seeks moist refuge in soil macro-pores.
Brown field slug *Deroceras invadens* or *D. laeve*  Photo: Michael Nash, SARDI	25–35 mm long, and usually brown all over with no distinct markings. Produces a clear mucus.	Rasping of leaves. Leaves a shredded appearance.	All year round, if conditions are moist.	Prefers warmer conditions and pastures. Less damaging than grey field and black keeled slugs.

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Snails				
Vineyard or common white snail *Cernuella virgata*  Photo: Michael Nash, SARDI	Coiled white shell with or without a brown band around the spiral. Mature shell diameter between 12–20 mm. Open, circular umbilicus*. Under magnification, regular straight scratches or etchings can be seen across the shell.	Shredded leaves where populations are high. Found up in the crop prior to harvest.	Active after autumn rainfall. Breeding occurs once conditions are moist (usually late autumn to spring).	Mainly a contaminant of grain. Congregates on summer weeds and up off the ground on stubble.
White Italian snail *Theba pisana*  Photo: Michael Nash, SARDI	Mature snails have coiled white shells with broken brown bands running around the spiral. Some individuals lack the banding and are white. Mature shell diameter between 12–20 mm. Semi-circular or partly closed umbilicus*. Under magnification, cross hatched scratches can be seen on the shell.	Shredded leaves where populations are high. Found up in the crop prior to harvest.	Active after autumn rainfall. Breeding occurs once conditions are moist (usually late autumn to spring).	Mainly a contaminant of grain. Congregates on summer weeds and up off the ground on stubble.
Conical or pointed snail *Cochlicella acuta*  Photo: Michael Nash, SARDI	Fawn, grey or brown. Mature snails have a shell length of up to 18 mm. The ratio of the shell length to its diameter at the base is always greater than two.	Shredded leaves where populations are high. Found up in the crop prior to harvest.	Active after autumn rainfall. Breeding occurs once conditions are moist (usually winter to spring).	Mainly a contaminant of grain. Can be found over summer on and in stubble and at the base of summer weeds.

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Small pointed snail *Prietocella barbara*  Photo: Michael Nash, SARDI	Fawn, grey or brown. Mature shell size of 8-10 mm. The ratio of its shell length to its diameter at the base is always two or less.	Shredded leaves where populations are high. Found up in the crop prior to harvest.	Active after autumn rainfall. Breeding occurs once conditions are moist (usually winter to spring).	A contaminant of grain, especially hard to screen from canola grain as the same size. Mainly found over summer at the base of summer weeds and stubble. Similar to slugs will go into soil macropores. Especially difficult to control with bait at current label rates.

*Umbilicus – a depression on the bottom (dorsal) side of the shell, where the whorls have moved apart as the snail has grown. The shape and the diameter of the umbilicus is usually a species-specific character.

Source: IPM Guidelines

7.9.1 Managing slugs and snails

Table 5 provides recommendations for the control of slugs in seedling crops.

Table 5: *Controlling slugs.*

Objectives	Pre-sowing	Germination – Vegetative
Find insects and damage Species of slugs	**High risk:** High rainfall areas >450 mm/annum. Above average spring–autumn rainfall. Cold wet establishment conditions. No till stubble retained. Summer volunteers. Previous paddock history of slugs. Soils high in clay and organic matter. Slugs are nocturnal and shelter during dry conditions and generally not visible.	**Damage:** Rasping of leaves. Leaves have a shredded appearance. Complete areas of crop may be missing. Slugs will eat all plant parts but the seedling stage is most vulnerable and this is when major economic losses can occur. Grey and brown field slugs are mainly surface active but the black keeled slug burrows and can feed directly on germinating seed.

Objectives	Pre-sowing	Germination – Vegetative
Monitor and record	Monitor with surface refuges to provide an estimate of active density. Refuges can include: terracotta paving tiles carpet squares or similar Use a 300 mm by 300 mm refuge when soil moisture is favourable (> 20%) as slugs require moisture to travel across the soil surface. Research has shown that slugs are attracted to the refuges from approximately 1 m hence numbers found can be used as numbers per m^2. Place refuges in areas of previous damage, after rainfall, on damp soil before sowing. Use 10 refuges per 10 hectares. Check the refuges early in the morning, as slugs seek shelter in the soil as it gets warmer. An alternative option to monitoring with refuges is to put out metaldehyde bait strips and check the following morning for dead slugs.	Monitor for plant damage. Slug populations are not even distributed in the field and are often clumped. Where crop damage is evident—inspect the area at night.
Natural enemies	Some species of carabid beetles can reduce slug populations but generally not below established economic thresholds. Free living nematodes that carry associated bacteria that cause slug death are thought to help reduce populations under certain field conditions. Many other soil fauna, such as are protozoa, may cause high levels of slug egg mortality under moist warm conditions however biological controls alone can not be solely relied on for slug control.	
Cultural control	Hard grazing of stubbles. Burning. Cultivation leaving a fine consolidated tilth. Removal of summer volunteers. Rolling at sowing. Early sowing for quick establishment.	
Thresholds	Thresholds have been established but should be used as a guide only. Also, take into account the field, the season, crop health and weather conditions.	Suggested thresholds per square metre: Grey field slug Canola 0.5–1.5 Cereals 5–15 Pulses 1–2 Black keeled slug Canola <1 Cereals 1–2 Pulses 1–2

Objectives	Pre-sowing	Germination – Vegetative
Chemical control	Baiting slugs is the only chemical option available to manage slugs. Molluscidial baits containing either metaldehyde or chelated iron are IPM compatible. Baits containing methiocarb are also toxic to carabid beetles—one of the few predators of slugs. Different responses to bait can be due to species behaviour. The value of applying bait after a significant rainfall event prior to sowing is still to be tested. For black keeled slugs—broadcast baits when dry or place with seed at sowing. For grey field slugs—broadcast baits Do not underestimate slug populations—always use rate that gives 25–30 per metre. Calibrate bait spreaders to ensure width of spread, evenness of distribution and correct rate.	Bait after/at sowing prior to crop emergence when soil is moist (i.e. >20% soil moisture). Re-apply baits to problem areas 3–4 weeks after first application if monitoring indicates slugs are still active. The number of baits/ha is more important than the total weight of bait/ha. Current research indicates that 250,000 bait points/ha is the minimum required for effective control.
Multi-pest interactions	Different species respond differently to environmental and field conditions leading to staggered emergence and need for repeated application under some conditions.	
Communicate and discuss management	Know paddock history and slug presence before sowing. Where retained stubble—graze or burn to control slugs before sowing. Control summer volunteers that may harbour slugs. Discuss optimum times for baiting and observations regarding population activity. Consult industry publications for up-to-date information of pest problems. No single method will provide complete control of slugs. Consider cultural and chemical control and work on pest control year-round to achieve a reasonable level of control.	

Source: IPM Guidelines

Table 6 provides recommendations for the control of snails in seedling crops.

MORE INFORMATION

Slug management Factsheet.

Table 6: *Controlling snails.*

Objectives	Pre-sowing	Seedling – Vegetative	Grain fill / Podding	Harvest
Find insects and damage Species of snails	**High risk:** Weedy fields Alkaline calcareous soils Retained stubble Wet spring, summer, autumn History of snails All species of snails congregate at the base of summer weeds or in topsoil. Pointed snail species can also be found at the base or up in stubble as well as inside stubble stems. Snails appear to build up most rapidly in canola, field peas and beans but can feed and multiply in all crops and pastures. Snails are most active after rain and when conditions are cool and moist. Snails are dormant in late spring and summer.	**Damage:** Snails consume cotyledons and this may resemble crop failure Shredded leaves where populations are high. Chewed leaf margins Irregular holes A wide range of snail sizes are an indication of snails breeding in the area. If most snails are the same size, snails are moving in from other areas. Round snails favour resting places off the ground on stubble, vegetation and fence posts. Pointed snails are found on the ground in shady places.	Snails can be found up in the crop prior to harvest. Check for snails under weeds or shake mature crops unto tarps	**Snails are predominantly a grain contaminant.** At harvest, snails move up in the crop and may shelter between grains or under leaves. They can also be found in windrows. The small pointed snail is especially hard to screen from canola grain due to similar size. Buyers will reject grain if: More than half a dead or one live snail is found in 0.5 litre of wheat. More than half a dead or one live snail is found in 200 gram pulse sample.
Monitor and record	Monitor snails regularly to establish their numbers, types and activity and success of controls Look for snails early morning or in the evening when conditions are cooler and snails are more active. Key times to monitor: 3–4 weeks before harvest to assess need for harvester modifications and cleaning After summer rains—check if snails are moving from resting sites Summer to pre-seeding—check numbers in stubble before and after rolling/slashing/cabling Monitoring technique: Sample 30 x 30 cm quadrat at 50 locations across the paddock. If two snail groups are present (round and conical), record the number of each group separately. To determine the age class of round snails, place into a 7 mm sieve box, shake gently and they will separate into two sizes: >7 mm (adults) and <7 mm (juveniles). Sieve boxes can be constructed from two stackable containers, e.g. sandwich boxes. Remove the bottom from one and replace by a punch hole screen. Suggested screen size is 7 mm round or hexagonal. Five sampling transects should be taken in each paddock. One transect is taken at 90° to each fence line whilst the fifth transect runs across the centre of the paddock. Take five samples (counts) 10 m apart along each transect. Record the size and number of the snails in each sample. Average the counts for each transect and multiple this figure by 10 to calculate the number of snails per m^2 in that area of the paddock.			
Natural enemies	Free living nematodes when carrying associated bacteria that causes snail death are thought to help reduce populations under certain field conditions.			

Objectives	Pre-sowing	Seedling – Vegetative	Grain fill / Podding	Harvest
Cultural control	Hard grazing of stubbles Cabling and/or rolling of stubbles—when soil temperature is above 35°. Burning—if numbers are very high and ensure hot, even burns. Cultivation leaving a fine consolidated tilth. Removal of summer weeds and volunteers.			Reduce contamination. Stripper fronts in medium to heavy crops. Raising cutting heights. Harvester modifications (see Snail fact sheet). Seed cleaning (see Snail fact sheet). Windrowing. Trials with windrowed barley resulted in reduced round snail contamination. Early windrowing when cool produces better results.
Thresholds	To control snails, apply a combination of treatments throughout the year.	Thresholds can be unreliable due to the interaction between weather, crop growth and snail activity. For example: high snail populations in the spring do not always relate to the number of snails harvested. Their movement into the crop canopy is dictated by weather conditions prior to harvest. Suggested thresholds for round snails: Cereals—20/m^2 Pulses and oilseeds—5/m^2 Suggested thresholds for small pointed snails: Cereals—40/m^2 Oilseeds—20/m^2 Baiting before egg lay is vital.		Thresholds to warrant harvester modifications are difficult to define. Contamination depends on snail types and size in relation to grain as well the position of snails in relation to cutting height.
Chemical control	Molluscidial baits containing either Metaldehyde or Chelated iron are IPM compatible. Apply to the bare soil surface when snails are active after autumn rain as early as March. Aim to control snails pre-season.	Mature snails larger than 7 mm in length or diameter will feed on bait but this can be less effective on juveniles. Baiting before egg lay is vital. Bait when snails are moving from resting sites after summer rains. Stop baiting 8 weeks before harvest to avoid bait contamination in grain. Bait rates need to be at the highest label rate to achieve a greater number of bait points. The actual number is yet to be determined; hence, label rates may be revised ion the future. Note that in cool, moist conditions, snails can move 30 m/week and treated fields can be re-invaded from fence lines, vegetation and roadsides.		Rain at harvest can cause snails to crawl down from crops.
Multi-pest interactions	Baits containing Methiocarb are toxic to a range of other invertebrates and beneficials.			

Objectives	Pre-sowing	Seedling – Vegetative	Grain fill / Podding	Harvest
Communicate and discuss management	Know paddock history and snail presence before sowing. Where retained stubble—graze, burn or bash to remove snails before sowing. Control summer volunteers and brassica weeds that may harbour snails. Consider harvester modifications id snails present at harvest. Discuss optimum times for baiting. Consult industry publications for up-to-date information of pest problems.			

Source IPM Guidelines

7.10 Wireworms and False wireworms

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 that are commonly called "click" beetles, coming 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*), but 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 pre- and post-emerging seedlings of all oilseeds, grain legumes and cereals, particularly in light, draining soils with a high organic content. Fine seedling crops like canola and linola are most susceptible.

The incidence of damage caused by wireworms and false wireworms is increasing with increasing use of minimum tillage and short fallow periods.

7.10.1 False wireworms

(Family *Tenebrionidae*; numerous species)

These insects are the larvae of native beetles that normally live in grasslands or pastures and cause little or no damage in this situation. In crops, they are mostly found in paddocks with high stubble and crop litter contents. They may affect all winter-sown crops.

There are a large and varied number of species, but the general characteristics of false wireworm are as follows.

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. There are several common groups (genera) of false wireworms found in south-eastern Australia:

- The grey or small false wireworm (*Isopteron* (*Cestrinus*) *punctatissimus*). The larvae grow to about 9 mm (3/8") in length. They are grey-green in colour, have two distinct protrusions from the last abdominal (tail) segment and tend to have a glossy or shiny exterior (Figure 29). 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 about 8 mm in length. The eggs are less than 1 mm in diameter. There are several species of this pest genus, although I. punctatissimus appears to be the species most associated with damage.

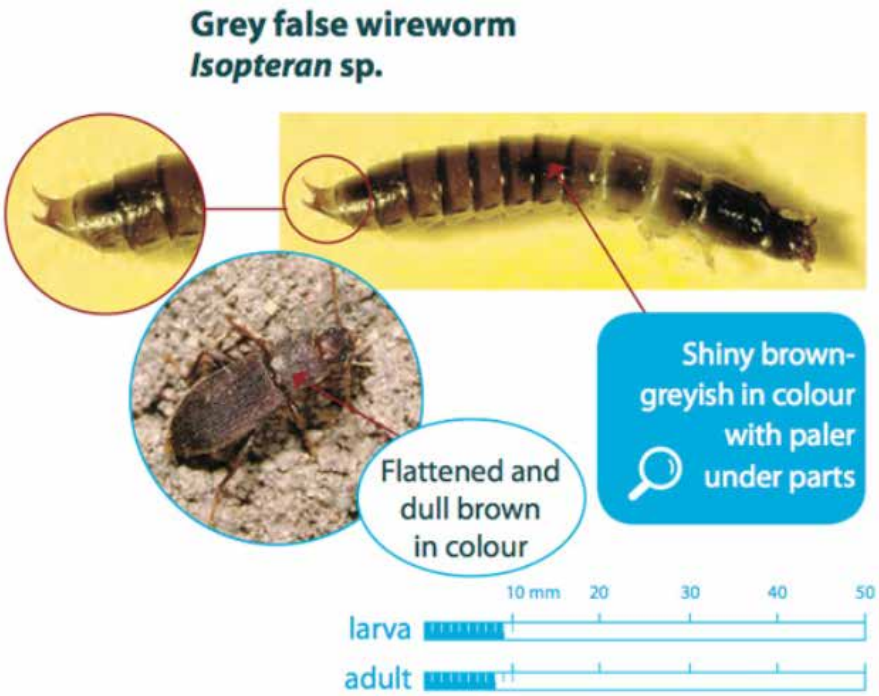


Figure 29: *Distinguishing characteristics of the grey false wireworm.*

Source: cesar

- The large or eastern false wireworm (*Pterohelaeus* spp.). These are 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 in colour, with tan or brown rings around each body segment, giving the appearance of bands around each segment. 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 a black shiny bodies (Photo 11).

Photo 11: *Eastern false wireworm adult beetle (left) and larva (right).*

Source: cesar

- The southern false wireworm (*Gonocephalum* spp.) grows to about 20 mm in length, and has similar body colours and marking to the large false wireworm. Adults are generally dark brown-grey, oval beetles, which sometimes have a coating of soil on the body (Figure 30). Adults have the edges of the body flanged, hence the common name "pie-dish" beetles.

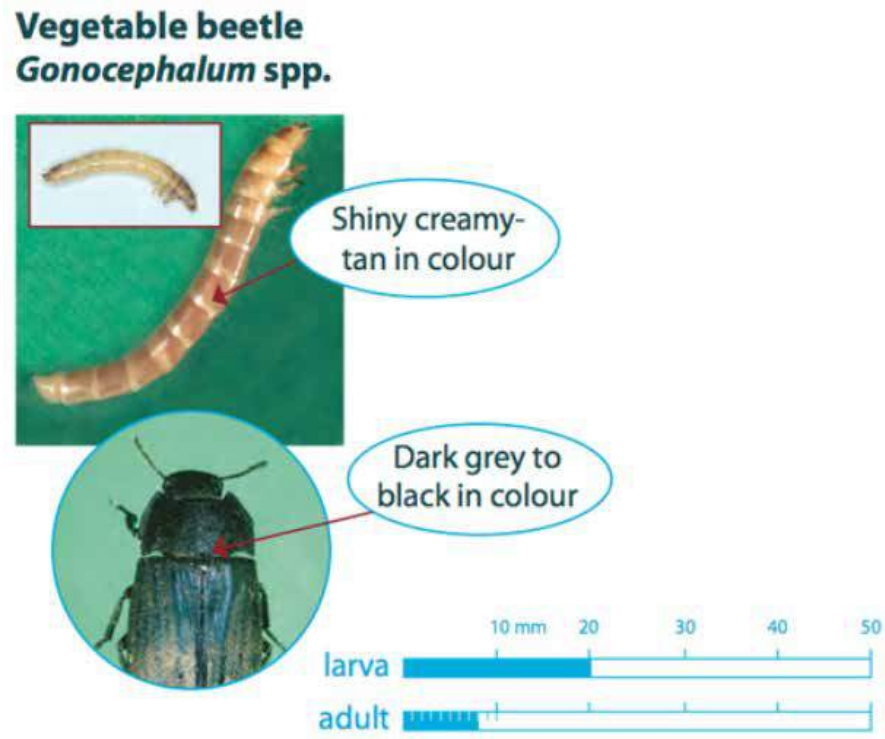


Figure 30: *Distinguishing characteristics of the southern false wireworm.*

Source: cesar

Biology

Usually only one generation occurs each year. However, some species may take up to 10 years to complete the life cycle. Adults emerge from the soil in December and January and lay eggs in or just below the soil surface, mostly in stubbles and crop litter. Hence, larvae are most commonly found in stubble-retained paddocks.

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. However, 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.

Nothing is known of the conditions that trigger the switch in the false wireworm feeding from organic matter/litter to plants. Significant damage is, however, likely to be associated with soils that remain dry for extensive periods of time. 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.

Damage caused by false wireworms

Affected crops may develop bare patches, which could be large enough to require re-sowing (Photo 12). Damage is usually greatest when crop growth is slow due to cold, wet conditions.

Photo 12: *False wireworm damage to pasture.*

Source: SARDI in cesar

Infestations of the small false wireworm can be as high as hundreds of larvae per square meter, although densities as low as five larger false wireworm larvae/m^2 can cause damage under dry conditions.

The larvae of the small false wireworm are mostly found damaging fine seedling crops shortly after germination. They feed on the hypocotyl (seedling stem) at or just below the soil surface. This causes the stem to be "ring-barked", and eventually the seedling may be lopped off or it wilts under warm conditions. Larger seedlings (e.g. grain legumes) may also be attacked, but the larvae appear to be too small to cause significant seedling damage.

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 above surface hypocotyl or cotyledons. In summer, adult beetles may also chew off young sunflower seedlings at ground level. Damage is most severe in crops sown into dry seedbeds and when germination is slowed by continued dry weather.

7.10.2 True wireworm

(Family *Elateridae*; numerous species)

These slow moving larvae tend to be less common, although always present, in broadacre cropping regions and are generally associated with wetter soils than that of false wireworms.

Larvae grow to 15–40 mm, are soft-bodied, flattened and slow moving; they can be distinguished 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 has serrated edges. Adults are known as "click" beetles, due to 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 31).

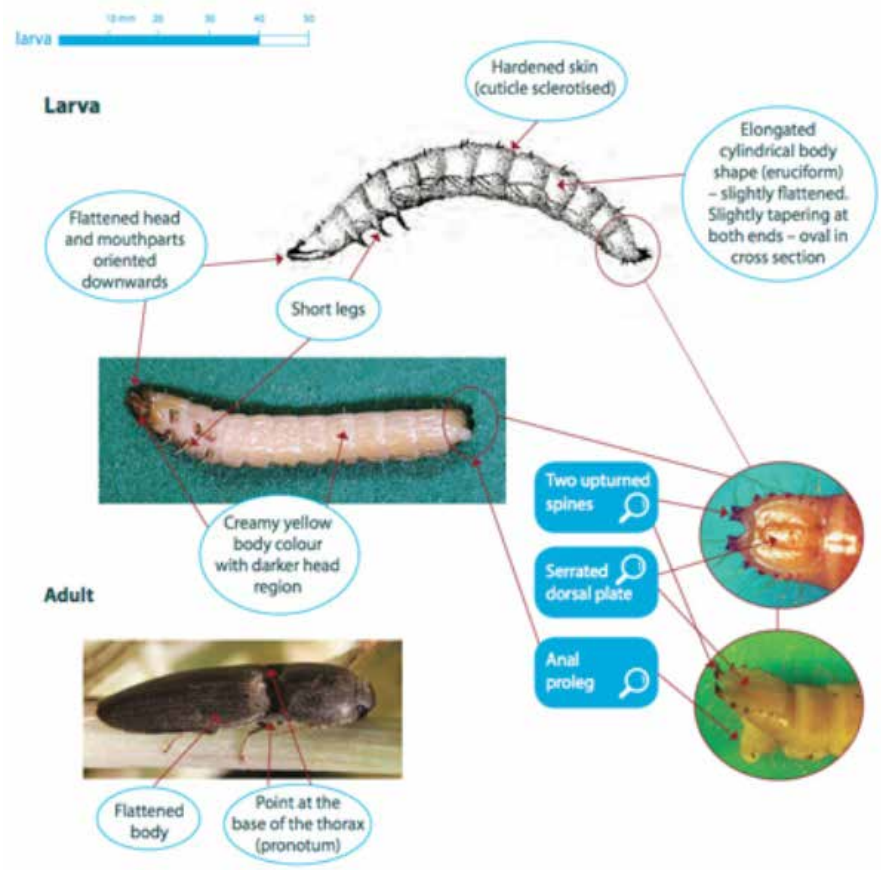


Figure 31: *Distinguishing characteristics of true wireworms.*

Source: cesar

Biology

There may be one or several generations per year, depending on species. Most damage occurs from April to August and adults emerge in spring. Wireworms prefer low-lying, poorly drained paddocks and are less common in dry soils. Larvae are reasonably mobile through the soil and will attack successive seedlings as they emerge. Adults are typically found in summer and autumn in bark, under wood stacks or flying around lights.

There is little known of the biology of most species, but one species (*Hapatesus hirtus*) is better understood. This species is known as the potato wireworm, although it is found in many other crop and pasture situations. It is very long-lived and probably takes five years or more to pass through all the wireworm stages before pupating and finally emerging as an adult beetle.

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 is probably why damage is often, but not always, most pronounced on tree-lines. The wireworms have a long life in the soil and are active all year, even in winter.

Damage

The damage caused by 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.

7.10.3 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.

Sampling

Crops should be sampled immediately before sowing. There are two methods available, although neither provides a 100% reliable method of detection. This is because larvae change their behaviours according to soil conditions, particularly soil moisture and temperature.

- Soil sampling. Take a minimum of five random samples from the paddock. Each sample should consist of the top 20 mm of a 0.50 m area of soil. Carefully inspect the soil for larvae. Calculate the average density per meter squared 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.
- Seed baits. Seed baits have been used successfully to sample true and false wireworms in Queensland and overseas. In Victoria, they have not been rigorously tested. Preliminary work has shown that they can be used to show the species of larvae present, and give an approximate indication of density. Take about 200–300 gm of a large seed bait, such as that of any grain legume, and pre-soak over 24 hours. Select five to 10 sites in the paddock and place a handful of the soaked seed into a shallow hole (50 mm), then cover with about 10 mm of soil. Mark each hole with a stake, and re-excavate each hole after about 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.

Detection

Larvae of the small false wireworms are relatively difficult, although not impossible, to see in grey and black soils because of their small size and dark colour. However, they can be found in the top 20 mm of dry soil by carefully examining the soil in full sunlight. Larvae of the other false wireworm species are more prominent because of their relatively pale colour and large size.

7.10.4 Control

Crop residues and weedy summer fallows favour survival of larvae and over-summering 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 population numbers. Seedbeds must be sampled prior to sowing if control is to be successful. Insecticides may be applied to soil or seed at sowing. Most chemicals registered for false wireworm control are seed treatments, although these may not be consistently reliable. They probably work best when the seedling grows rapidly in relatively moist soils. Adults may also be controlled with insecticide incorporated into baits. If damage occurs after sowing, no treatment is available, other than re-sowing bare patches with an insecticide treatment. The critical periods for control of false wireworm are shown in Figure 32 below. [36]

36 G McDonald (1995) Wireworms and false wireworms. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms

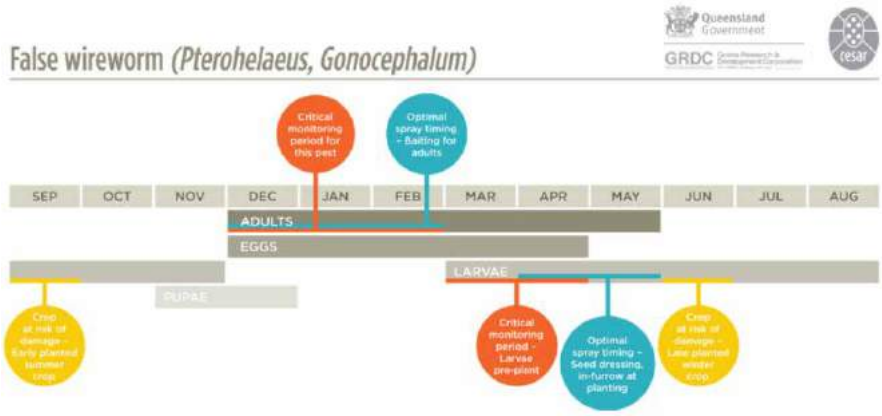


Figure 32:

Source: cesar

7.11 *Helicoverpa* spp.

Helicoverpa spp. are frequently found in winter cereals, usually at levels too low to warrant control, but occasionally numbers may be sufficiently high to cause economic damage. Virtually all *Helicoverpa* present are *H. armigera* (Photo 13), which has developed resistance to many of the older insecticide groups. It is not unusual to find both *Helicoverpa* and armyworm in cereal crops, so correct identification of the species present is important.

Photo 13: *Helicoverpa armigera.*

Source: Department of Agriculture and Fisheries Queensland

There are two species that are pests of field crops, particularly grain legumes, summer grains and cotton—*H. armigera* and *H. punctigera*. The latter is more common in southern cropping regions.

Eggs are 0.5 mm in diameter and change from white to brown to a black head stage before hatching. Newly hatched larvae are light in colour with tiny dark spots and dark heads. As larvae develop, they become darker and the darker spots become

MORE INFORMATION

False wireworms in seedling crops

more obvious. Both species of helicoverpa look the same at the egg and small larvae stages. Medium larvae develop lines and bands running the length of the body and are variable in colour. *H. armigera* have a saddle of darker pigment on the fourth segment and at the back of the head and dark-coloured legs. *H. punctigera* have no saddle and light-coloured legs. Large larvae of *H. armigera* have white hairs around the head; *H. punctigera* have black hairs around the head. Pupae are found in soil underneath the crop. Healthy pupae wriggle violently when touched. *H. armigera* pupal tail spines are more widely spaced than those of *H. punctigera*. Moths are a dull light brown with dark markings and are 35 mm long. *H. armigera* has a small light or pale patch in the dark section of the hindwing, while the dark section is uniform in *H. punctigera*. Forewings are brown in the female and cream in the male. [37]

7.11.1 Damage caused by pest

Helicoverpa do not cause the typical head-cutting damage of armyworms. Larvae tend to graze on the exposed tips of a large number of developing grains, rather than totally consuming a low number of whole grains, thus increasing the potential losses. Most (80–90%) of the feeding and crop damage is done by larger larva (the final two instars). Larvae feed on leaves but are most damaging when feeding on growing terminals, buds or squares, flowers, pods, seed and/or fruit. This includes direct losses through shedding and reduced quality. [38]

7.11.2 Management of insect pest

Check for larvae on the plant throughout the growing season. Monitoring can be done in conjunction with sampling for armyworm.

Chemical control

H. armigera has developed resistance to a wide range of insecticides; however, several products are now registered for both species that have reduced impacts on natural enemies in the crop. Larvae are best targeted when smaller than 7 mm. Small larvae (<7 mm) can be controlled with biopesticides (e.g. nucleopolyhedrovirus [NPV]). Larger larvae are more difficult to control than small larvae, and NPV is most effective when larvae <13 mm long are targeted. *H. armigera* has historically had high resistance to pyrethroids, and control of medium-large larvae using pyrethroids is not recommended. [39]

Natural enemies

All stages of the Helicoverpa lifecycle are attacked by a wide range of predators, parasitoids and pathogens, and conserving these in the crop through the avoidance of broad-spectrum insecticides can help prevent/minimise the need for insecticide treatments. Predators of Helicoverpa eggs and larvae include spined predatory bug, glossy shield bug, damsel bug and big-eyed bug. [40]

37 DAFQ (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

38 DAFQ (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

39 DAFQ (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

40 DAFQ (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

Nematode management

Key messages:

- Nematodes (or roundworms) are one of the most abundant life forms on earth. In cropping situations they can range from being beneficial to detrimental to plant health.
- Well-managed rotations with resistant or non-host break crops are vital for minimising yield losses due to nematode infections. Avoid consecutive host crops to limit populations.
- Choose crop varieties with high resistance ratings, which result in fewer nematodes remaining in the soil to infect subsequent crops.
- Reducing root-lesion nematodes (RLN) and cereal cyst nematodes (CCN) can lead to higher yields in following cereal crops.
- Healthy soils and good nutrition can, to some extent, ameliorate RLN and CCN damage through good crop establishment, and healthier plants recover more readily from infestation.
- Observe crop roots to monitor development of symptoms.
- Weeds can host parasitic nematodes and control of host weed species and crop volunteers is important.
- Most durum varieties are moderately susceptible to the commonly found *P. neglectus* and are moderately resistant to *P. thornei* but vary more widely in resistance to CCN.

8.1 Root-lesion nematode (*Pratylenchus* spp.)

Key points:

- Root-lesion nematodes (RLN) are microscopic worm-like animals that extract nutrients from plants causing yield loss.
- Know your enemy—soil test to determine whether RLN are an issue and which species are present.
- Select wheat varieties with high tolerance ratings to minimise yield losses in RLN-infected paddocks, although there are only small differences in rankings between durum varieties.
- To manage RLN populations, it is important to increase the frequency of RLN-resistant crops in the rotation.
- Avoid crops or varieties that allow the build up of large populations of RLN in infected paddocks.
- Monitor the impact of your rotation.
- Sow early where possible to 'get ahead' and maximise yield.
- Manage fertility to maximise nutrition, particularly early in the growing season.
- Control volunteer hosts and weeds during late summer/early autumn and in break crops. [1]

RLN (*Pratylenchus* spp.) are microscopic plant parasites that are soil-borne, ~0.5 to 0.75 mm in length and will feed and reproduce inside roots of susceptible crops or plants potentially causing yield loss. The main RLN species in the southern region are *Pratylenchus neglectus* and *P. thornei* (Photo 1). The *Pratylenchus* species present in the soil will affect choice of management practices, in particular rotations. RLN have a wide host range and can multiply on cereals, oilseeds, pulses and pastures as well as on broadleaf and grass weeds. [2]

1 A Wherrett, V Vanstone Root-lesion nematode. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/root-lesion-nematode

2 GRDC (2015) Tips and tactics. Root-lesion nematodes. Grains Research and Development Corporation, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

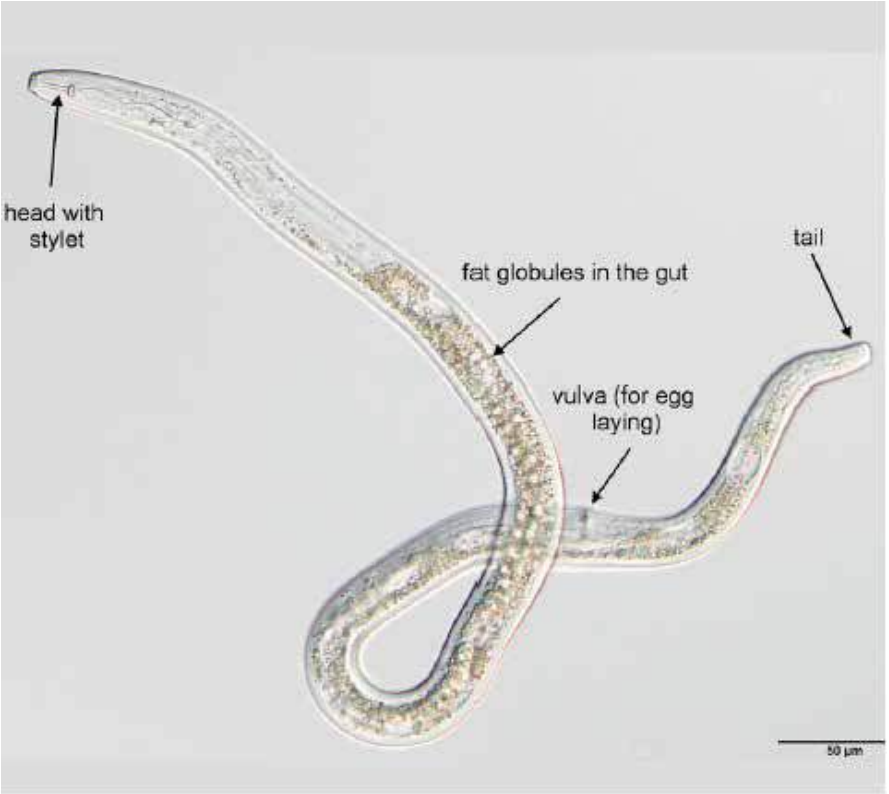


Photo 1: *A Pratylenchus thornei adult female viewed under the microscope. The nematode is approximately 0.65 mm long. The syringe-like 'stylet' at the head end is used for extracting nutrients from the plant root.*

Source: Grains Research and Development Corporation

The extent of RLN occurrence across Australia has recently been estimated (Figure 1).

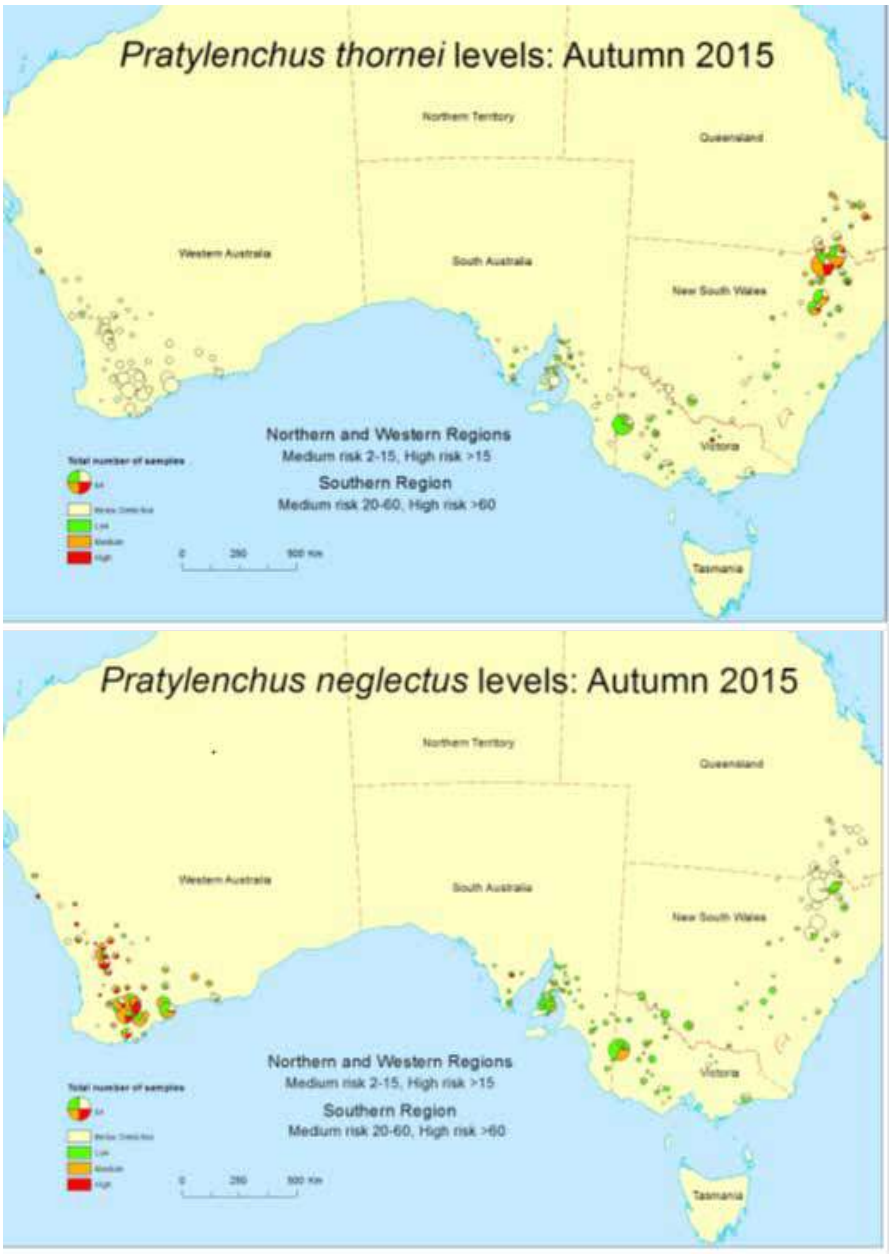


Figure 1: *The distribution and risk of causing yield loss of samples submitted to PreDictaB, SARDI in autumn 2015 for (top)* Pratylenchus thornei *and (bottom)* P. neglectus.

Maps are reproduced with permission from SARDI. Source: GRDC

RLN emerged as potential problems in cereals (and other crops) after management strategies were implemented to control CCN and take-all. Yield losses in the southern region are variable and currently under investigation, but present estimates for intolerant varieties indicate a 1% yield loss per two nematodes per gram soil. *Pratylenchus thornei* (Figure 1) occurs throughout the root zone and is often more damaging than *P. Neglectus*, which tends to be concentrated in the top 15 cm of the soil.

RLN move freely between roots and soil if the soil is moist. 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. [3]

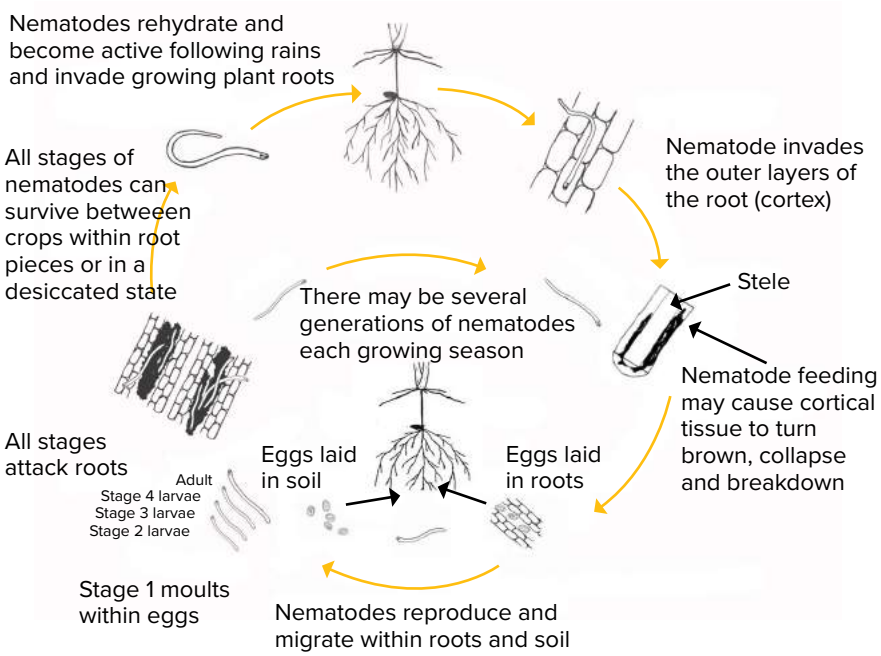


Figure 2: *Disease cycle and damage of root-lesion nematode. Adapted from GN Agrios (1997) Plant pathology, 5th edn (Academic Press: New York); illustration by Kylie Fowler.*

Source: Grains Research and Development Corporation

Yield losses caused by RLN are correlated with the population of these nematodes present in the soil at sowing, the tolerance of the wheat variety and the date of sowing. *P. neglectus* and *P. thornei* can cause yield losses of up to 40% in broadacre field crops in southern Australia if populations are high and intolerant varieties are sown late, but most yield losses are less than 15%. [4]

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* reduced grain yield by 2–8% (Table 1). [5]

3 GRDC (2015) Tips and tactics. Root-lesion nematodes. Grains Research and Development Corporation, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

4 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

5 GRDC (2015) Tips and tactics. Root-lesion nematodes. Grains Research and Development Corporation, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

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.*

	P. thornei		P. neglectus	
Year	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

Source: Grains Research and Development Corporation

While having some susceptibility, durum varieties can generally be regarded as having among the best levels of resistance to both species of RLN relative to commonly grown wheat varieties in the Southern Region. Consult variety sowing guides for more information.

A survey of 385 paddocks in western Victoria during 2014 and 2015 found that RLN are widespread, being present in up to 98% of paddocks with yield losses possible in many paddocks (Table 2). Based on this data, annual losses due to root lesion nematodes was estimated at $2 million to $13 million, depending on the season. [6]

Table 2: *Percentage of paddocks (n = 385) surveyed in three regions in western Victorian during 2014 and 2015 within each root-lesion nematode risk category (below detection limit [BDL], low, medium and high) and the corresponding potential yield loss (%) caused by root-lesion nematodes.*

PreDicta B risk categories		Victorian region (%)			
Risk Category	Number of RLN per gram of soil	Mallee (n=173)	Wimmera (n=182)	Western District (n=30)	Potential yield loss (%)
Root lesion nematode: *Pratylenchus neglectus*					
BDL	<0.1	2	5	37	<2
Low	0.1–20	77	75	60	0–10
Medium	20–60	18	20	3	0–20
High	>60	3	0	0	0–40
Root lesion nematode: *Pratylenchus thornei*					
BDL	<0.1	72	47	73	<2
Low	0.1–20	27	46	27	0–10
Medium	20–60	0	6	0	0–20
High	>60	1	1	0	0–40

Source: Grains Research and Development Corporation

As the symptoms caused by RLN are not as distinct as for the other cereal root diseases it is advisable to have soil tested to determine the likely impact of this pest.

The impact of drought on nematode multiplication is not well understood, however stressed plants are more susceptible to attack. In contrast shorter growing season and reduced root growth can reduce nematode numbers. [7]

VIDEOS

WATCH: GCTV6: Root-lesion nematodes.

WATCH: Understanding root-lesion nematodes.

6 G Hollaway, M McLean J Fanning (2016) Cereal disease management in Victoria 2016. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-disease-management-in-Victoria-2016

7 PIRSA Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

FAQ

8.1.1 Varietal resistance and 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).

Durum varieties consistently show higher levels of resistance to the RLN *P. thornei* than bread wheat and barley varieties. The average *P. thornei* population remaining after a single durum crop is ~40-80% less than after EGA Gregory and 80–90% less than after a single season of Strzelecki. Indications are that DBA Lillaroi, DBA Aurora(D) and Tjilkuri(D) have similar levels of *P. thornei* resistance as Caparoi(D) and EGA Bellaroi(D). Jandaroi(D) is generally the least *P. thornei*-resistant durum variety but is still similar to the most resistant commercial bread wheat options. [8] Figure 3 shows the relative build up on *P. thornei* population in three durum varieties and two bread wheat varieties, as measured in field trials conducted by Northern Grower Alliance and New South Wales (NSW) Department of Primary Industries from 2009 to 2014. Hyperno(D), Caparoi(D) and EGA Bellaroi(D) resulted in significantly lower final populations of *P. thornei* than EGA Gregory. Strzelecki resulted in significantly larger populations of *P. thornei* than all other varieties graphed.

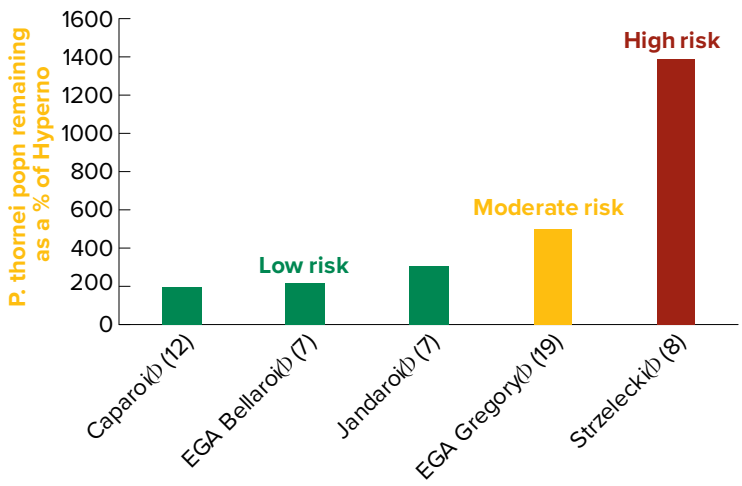


Figure 3: *Relative P. thornei build up following a single crop of durum and bread wheat varieties, expressed as a percentage of the moderately resistant durum variety Hyperno(D). Number in brackets indicates the number of trials for each variety.*

Source: Grains Research and Development Corporation

Durum has a low to medium hosting ability for *P. thornei* and high for *P. neglectus*. [9]

Durum varieties differ in tolerance to *P. thornei*. Figures 4 and 5 show the yield impact of low versus high levels of *P. thornei* on different wheat varieties in trials undertaken in northern NSW and south-eastern Queensland. Significant levels of yield impact were seen in EGA Bellaroi(D) in 2012 in northern NSW (-0.6t/ha; Figure 3) and DBA Lillaroi (-0.6t/ha), and in Tjilkuri(D) (-0.4t/ha) in 2015 in south-eastern Queensland (Figure 4). Caparoi(D) (and potentially Hyperno(D) and DBA Aurora(D)) may be better options for durum production in paddocks with high levels of *P. thornei*. [10]

8 B Burton, R Norton R Daniel (2014) Root lesion nematodes cereal variety and rotational crop impacts on yield and nematode numbers. GRDC update papers. Grains Research and Development Corporation, August 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Root-lesion-nematodes-cereal-variety-and-rotational-crop-impacts-on-yield-and-nematode-numbers

9 GRDC (2015) Root lesion nematodes Southern Region Tips and Tactics Fact Sheet www.grdc.com.au/TT-RootLesionNematodes

10 B Burton, R Norton R Daniel (2014) Root lesion nematodes cereal variety and rotational crop impacts on yield and nematode numbers. GRDC update papers. Grains Research and Development Corporation, August 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Root-lesion-nematodes-cereal-variety-and-rotational-crop-impacts-on-yield-and-nematode-numbers

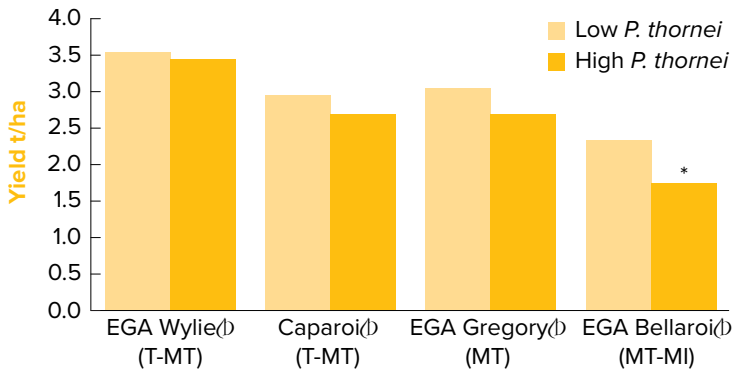


Figure 4: *Yield impact from P thornei near Yallaroi(b), northern NSW, in 2012 with varieties ranked from left to right in decreasing P. thornei tolerance ranking. Letters in brackets are the tolerance rankings P. thornei (T: tolerant; MT: moderately tolerant; MI: moderately intolerant; 2016 Queensland Variety Guide). Light columns show variety yield with a starting population of 1.9 P. thornei/g soil (i.e. low P. thornei). Dark columns show yield when starting population was 19 P. thornei/g soil (i.e. high P.thornei). *= significant yield loss in variety under increased P. thornei population, e.g. EGA Bellaroi(b).*

Source: Grains Research and Development Corporation

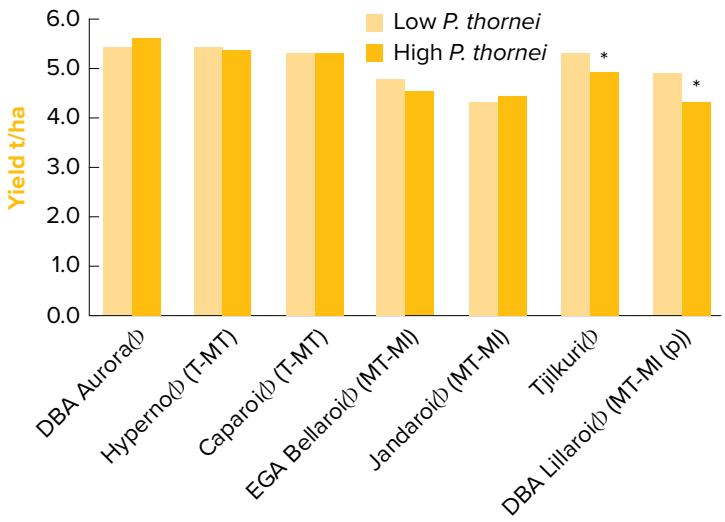


Figure 5: *impact from P. thornei near Macalister, south-eastern Queensland, in 2015 with varieties ranked from left to right in decreasing P. thornei tolerance ranking. Letters in brackets are the tolerance rankings P. thornei (T: tolerant; MT: moderately tolerant; MI: moderately intolerant; 2016 Queensland Variety Guide). NB: No available tolerance ranking for DBA Aurora(b) and Tjilkuri(b). Light columns show variety yield with a starting population of 2.7 P. thornei/g soil (i.e. low P. thornei). Dark columns show yield when starting population was 29 P. thornei/g soil (i.e. high P. thornei). *= significant yield loss in variety under increased P. thornei population, e.g. Tjilkuri(b) and DBA Lillaroi.*

Source: Grains Research and Development Corporation

8.1.2 Damage caused by pest

Although symptoms of RLN damage in wheat can be dramatic, they can be easily confused with nutritional deficiencies and/or moisture stress.

Damage from RLN results in brown root lesions but these are difficult to see and can also be caused by other organisms. Root systems are often compromised with reductions in root branching and quantities of root hairs together with a reduced ability to penetrate deeply into the soil profile. RLN create an inefficient root system that impairs the ability of the plant to access nutrition and water.

Visual damage above-ground from RLN in wheat is non-specific. Lower leaf yellowing is often observed together with reduced tillering and a reduction in the amount of crop biomass. Symptoms are more likely to be observed later in the season, particularly when the crop is reliant on sub soil moisture. Clear symptoms are generally not seen in other crops.

In the early stages of RLN infection, localised patches of poor performing wheat may be observed (Photo 2). Soil testing of these patches may help to determine 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. [11]

Photo 2: *Above-ground symptoms of root-lesion nematode are often indistinct and difficult to identify. Affected plants (centre-left) generally show poor vigour and are often stunted, and cereals tiller poorly.*

Source: Grains Research and Development Corporation

Below-ground symptoms

Because above-ground 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 of 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 (Photo 3). The root cortex (or outer root layer) will be damaged and it may disintegrate. [12]

11 B Burton, R Norton R Daniel (2014) Root lesion nematodes cereal variety and rotational crop impacts on yield and nematode numbers. GRDC update papers. Grains Research and Development Corporation, August 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Root-lesion-nematodes-cereal-variety-and-rotational-crop-impacts-on-yield-and-nematode-numbers

12 GRDC (2015) Tips and tactics. Root-lesion nematodes. Grains Research and Development Corporation, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

Photo 3: *Symptoms of root-lesion nematode on wheat roots include darkening of the cortex and lack of root hairs.*

Source: Grains Research and Development Corporation

8.1.3 Thresholds for control

In the southern region, yield losses are variable, however, present estimates for intolerant varieties indicate a 1% yield loss per two nematodes per gram soil. The damage threshold has been estimated at 2,000 nematodes/kg soil (or 2/g soil). Control is warranted for paddocks with populations over this density threshold. [13]

Table 3 shows the estimated yield loss from *Pratylenchus* spp. in each risk categories.

Table 3: *Pratylenchus spp. yield loss categories using PreDicta B soil tests.*

Risk category	P. neglectus/g soil	P. thornei/g soil	Estimated % yield loss
Below detection limit	< 1	< 1	-
Low	1–20	1–20	0–10
Medium	20–60	20–60	5–20
High	>60	>60	10–40

Source: Primary Industries and Regions South Australia

8.1.4 Management of root-lesion nematodes

The yield loss caused by RLM is directly related to the number of nematodes present in a paddock. A pre-sowing root disease test is the best way to identify paddocks at risk of damage. Should damaging numbers be identified then appropriate

13 GRDC (2015) Tips and tactics: Root lesion nematodes southern region, www.grdc.com.au/TT-RootLesionNematodes

control strategies, including rotation to resistant crops, can be implemented to minimise loss. [14]

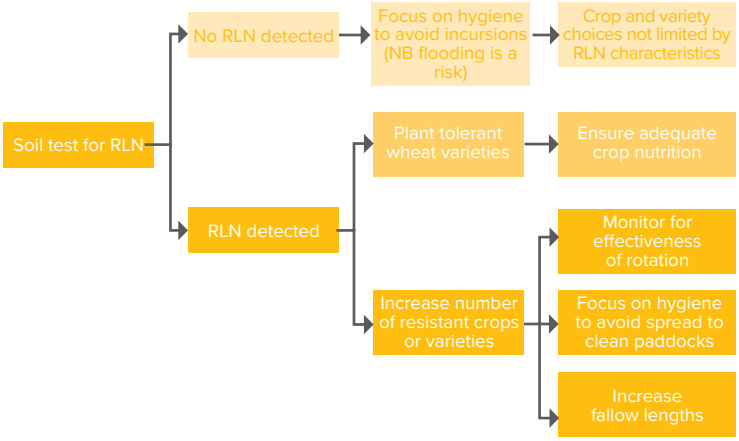


Figure 6: *Root-lesion nematode management flow-chart.*

Source: Grains Research and Development Corporation

Soil testing

The critical first step in the management of RLN is to test your soil and determine whether or not you even have the issue (Figure 6). Testing of soil samples is most commonly conducted via DNA analysis (commercially available as the PreDicta B test from the South Australian Research and Development Institute) with sampling to depths of 0–15 or 0–30 cm. Vertical distribution of *P. thornei* in soil is variable. Some paddocks have 'relatively' uniform populations down to 30 or 60 cm, some will have highest *P. thornei* counts in the 0–15 cm layer whilst other paddocks will have *P. thornei* populations increasing at deeper depths e.g. 30–60 cm. Although detailed knowledge of the distribution may be of some value, the majority of on-farm management decisions will be based on presence or absence of *P. thornei* with sampling at 0–15 or 0–30 cm depth providing that information. [15]

Management:

- Manage RLN by maintaining nematode numbers below threshold levels by growing resistant crops and varieties.
- In heavily infested paddocks, resistant crops or varieties should be grown for one or two years to decrease RLN populations.
- Hosting ability may vary between crop varieties. It is therefore important to check a current crop variety guide from your state department of agriculture or the National Variety Trials website for resistance and tolerance ratings.
- Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.
- Weeds can play an important role in the increase and/or persistence of nematodes in crops and pastures. Therefore, poor control of susceptible weeds will compromise the use of resistant crop rotations for RLN management. [16]

14 G Hollaway, M McLean J Fanning (2016) Cereal disease management in Victoria 2016. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-disease-management-in-Victoria-2016

15 B Burton, R Norton R Daniel (2014) Root lesion nematodes cereal variety and rotational crop impacts on yield and nematode numbers. GRDC update papers. Grains Research and Development Corporation, August 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Root-lesion-nematodes-cereal-variety-and-rotational-crop-impacts-on-yield-and-nematode-numbers

16 GRDC (2015) Tips and tactics. Root-lesion nematodes. Grains Research and Development Corporation, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

VIDEOS

WATCH: Root lesion nematodes—What can I do?

WATCH: Crop variety effect on nematode.

MORE INFORMATION

GRDC Tips and tactics: Root-lesion nematode – Southern region

Strategies:

1. **Nematicides**: there are no registered nematicides for RLN in broadacre cropping in Australia. Screening of potential candidates continues to be conducted but RLN are a very difficult target with populations frequently deep in the soil profile.
2. **Nutrition**: damage from RLN reduces the ability of cereal roots to access nutrients and soil moisture and can induce nutrient deficiencies. Under-fertilising is likely to exacerbate RLN yield impacts however over-fertilising is still unlikely to compensate for a poor variety choice.
3. **Variety choice and crop rotation:** *These are currently our most effective management tools for RLN.* However, the focus is on two different characteristics:
4. *tolerance*—the ability of the variety to yield under RLN pressure; and
5. *resistance*—the impact of the variety on the build-up of RLN populations.
6. NB varieties and crops often have varied tolerance and resistance levels to *Pt* and *Pn*.
7. **Fallow:** RLN populations will generally decrease during a 'clean' fallow but the process is slow and expensive in lost 'potential' income. Additionally, long fallows may decrease mycorrhizal levels and create more cropping issues than they solve. [17]

Cultural control

Crop rotation with resistant crops such as grain sorghum, millet, sunflower and canary will reduce the numbers of nematodes in the soil to a level where susceptible wheat varieties can be grown, but will not eliminate them completely. [18]

8.2 Cereal cyst nematode

Cereal cyst nematode (CCN; *Heterodera avenae*) is a pest of graminaceous crops worldwide. This nematode is a significant issue for growers across eastern Australia and becomes more problematic in areas where intensive cereal cropping occurs. CCN will only infect, feed and develop on cereals and other grasses (particularly wild oat). Non-cereal crops will not host the nematode, so are useful in rotations to limit damage caused to cereals. [19]

Though durum is not the most susceptible cereal crop to CCN buildup, its use in a crop sequence will not provide a complete break. [20] The Southern Region durum varieties most commonly grown range from MS to MS/S in reaction to CCN and while not as susceptible as some hard wheat varieties, must be carefully considered in high risk situations.

In a survey of 385 paddocks in western Victoria during 2014 and 2015, CCN was identified in 4% and 12% of paddocks in the Wimmera and Mallee, respectively, showing the effect of good control through the cultivation of resistant cereal varieties and crop rotation (Table 4). However, if CCN levels increase large yield losses are possible. [21]

17 B Burton, R Norton R Daniel (2014) Root lesion nematodes cereal variety and rotational crop impacts on yield and nematode numbers. GRDC update papers. Grains Research and Development Corporation, August 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Root-lesion-nematodes-cereal-variety-and-rotational-crop-impacts-on-yield-and-nematode-numbers

18 DAF QLD (2015) Wheat—diseases, physiological disorders and frost, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

19 A Wherrett, V Vanstone. Cereal cyst nematode. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/cereal-cyst-nematode

20 Tony Craddock. (2016). Personal Communication.

21 G Hollaway, M McLean J Fanning (2016) Cereal disease management in Victoria 2016. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-disease-management-in-Victoria-2016

Table 4: *Percentage of paddocks (n = 385) surveyed in three regions in western Victorian during 2014 and 2015 within each nematode risk category (below detection limit [BDL], low, medium and high) and the corresponding potential yield loss (%) due to cereal cyst nematode.*

PreDicta B risk categories		**Victorian region (%)**			
Risk category	Number of CCN per gram of soil	Mallee (n=173)	Wimmera (n=182)	Western District (n=30)	**Potential yield loss (%)**
Cereal cyst nematode (*Heterodera avenae*)					
BDL	<0.05	96	88	100	<5
Low	0.05–5	4	9	0	5–25
Medium	5–10	0	2	0	10–50
High	>10	0	1	0	15–70

Source: Grains Research and Development Corporation

Figure 7 illustrates the CCN lifecycle. CCN juveniles hatch from eggs contained in the cysts remaining from previous seasons; hatching occurs in response to lower temperatures and autumn rains. Hatching is delayed by late breaks or dry autumns and this increases the risk of crop damage. Once hatched the young nematodes seek out the roots of host plants. While the male nematodes remain free-living in the soil, the females penetrate roots and begin feeding. Following mating, the females produce eggs within their body. As the season progresses the females remain feeding at the same infection site and begin to swell into the characteristic white spheres. This process takes six to nine weeks, and the CCN females remain like this until the host plant begins to senesce. The females die and their cuticle hardens and turns brown to form a cyst. Cysts are particularly hardy, and remain in the soil over summer until temperatures fall and the autumn rains begin which stimulates hatching of the next generation. CCN have only one life cycle per year. However, each cyst contains several hundred eggs, so populations can increase rapidly on susceptible cereals. [22]

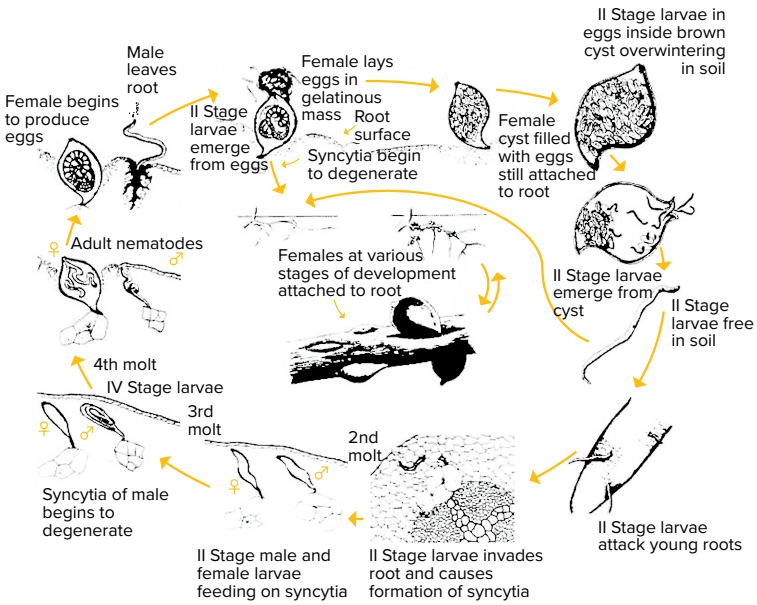


Figure 7: *Cereal cyst nematode life cycle and damage to plants. GN Agrios (1997) Plant pathology, 4th edition (Academic Press: New York).*

Source: Grains Research and Development Corporation

22 A Wherrett, V Vanstone. Cereal cyst nematode. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/cereal-cyst-nematode

Each year approximately 80% of nematodes hatch from cysts after the autumn break, while the remaining 20% stay dormant until the following season. This is why it will take at least two years with break crops to control CCN. However, under dry (drought) conditions up to 50% of nematodes remain dormant, and an extra year of break crop is advisable. [23]

8.2.1 Varietal resistance or tolerance

Continually check regional disease guides for updates on this data as ratings change annually as more data is collected. All durum varieties are moderately susceptible to CCN (Table 5).

Table 5: *Resistance of major durum varieties to common cereal diseases in South Australia for 2017.*

Durum wheat variety	Cereal cyst nematode resistance	Root lesion nematodes			
		P. neglectus	*P. thornei*		
Aurora(D)	MSS	MS	RMR		
Caparoi(D)	MS	MSS	MR		
Hyperno(D)	MS	MS	RMR		
Saintly(D)	MS	MS	MR		
Tjilkuri(D)	MS	MS	MR		
WID802(D)	MS	MS	MS		
Abbreviations					
R	Resistant	MR	Moderately resistant	MS	Moderately susceptible
S	Susceptible	VS	Very susceptible	MI	Moderately intolerant
I	Intolerant	-	Uncertain		

Source: Primary Industries and Regions South Australia

8.2.2 Damage caused by pest

The symptoms of CCN infection can be readily recognised. Above-ground, patches of unthrifty yellowed and stunted plants can be observed (Photo 4), which often gives the crop a 'patchy' appearance. Planting a susceptible crop in successive years will result in these patches becoming larger with time. [24]

23 G Hollaway (1996) Cereal root diseases. Agriculture Victoria, January 1996, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

24 A Wherrett, V Vanstone (2017) Cereal cyst nematode. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/cereal-cyst-nematode

Photo 4: *Cereal cyst nematide will cause distinct patches of yellowed and stunted plants. Note the likeness of symptoms to poor nutrition or water stress.*

Source: Soil Quality Pty Ltd

Closer examination of the roots will reveal symptoms that are typical of CCN, with wheat roots 'knotted' (Photo 5). Development of root systems is retarded and shallow. Symptoms can be confirmed at flowering time in spring, when characteristic white cysts (1–2 mm in diameter) can be seen with the naked eye if roots are carefully dug and washed free of soil (Figure 6). These are the swollen bodies of the female CCN, each containing several hundred eggs. [25]

Photo 5: *Cereal cyst nematodes produce 'knotting' of wheat and barley roots.*

Source: Soil Quality Pty Ltd

25 G Hollaway (1996) Cereal root diseases. Agriculture Victoria, January 1996, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

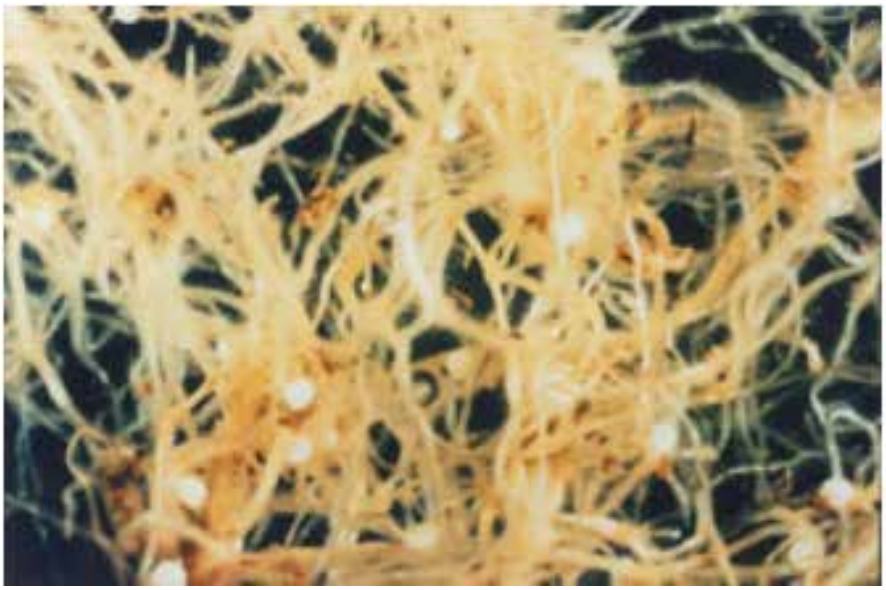


Photo 6: *Cereal cyst nematode-infected root system with characteristic white cysts.*

Source: Agriculture Victoria

8.2.3 Thresholds for control

Just two CCN eggs per of gram soil can cause significant economic loss to intolerant cereal crops. Levels of one to five eggs per gram of soil can reduce yield of wheat and oat by up to 20%. [26]

8.2.4 Management of cereal cyst nematode

As with other nematodes, there is no effective or economically feasible means of controlling CCN through chemical application. Chemical nematicides are expensive to use, toxic to humans and the success of applications are often highly variable. CCN is best controlled through effective rotation management. [27]

Only 70–80% of eggs hatch each season, regardless of the crop host. As a result, it can take several years for high CCN levels to be reduced by rotation with resistant or non-host crops. Plan ahead and make sure there is at least a two-year disease break following susceptible cereals. Timing of host removal is critical when establishing a disease break. In calculating the critical date to chemical fallow or remove host species from break crops consideration should be given to the time taken for host plants to die after herbicide application. Nematodes will continue to feed until the plant is dead.

Host plants, particularly susceptible self-sown cereals, must be controlled before the nematodes have completed the development of eggs. This is approximately 10 weeks after the autumn break (Figure 8). [28]

26 A Wherrett, V Vanstone. Cereal cyst nematode. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/cereal-cyst-nematode

27 A Wherrett, V Vanstone. Cereal cyst nematode. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/cereal-cyst-nematode

28 G Hollaway (1996) Cereal root diseases. Agriculture Victoria, January 1996, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

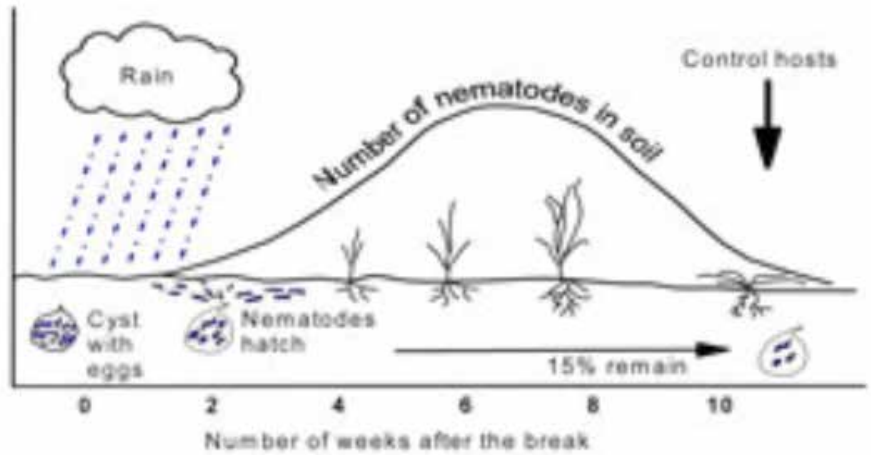


Figure 8: *Timing of the cereal cyst nematode life cycle in terms of the autumn break.*

Source: Agriculture Victoria

The use of resistant cereals and non-host crops, or fallow in rotations as part of a two-year break, is an effective method to control CCN.

Disease breaks for cereal cyst nematode:

- Grass-free pulse and oilseed crops or legume pasture.
- Resistant cereals – all durum varieties are moderately susceptible to CCN (see the Cereal Diseases Guide for a list of CCN-resistant cereal varieties).
- Chemical fallow prepared early in the season before nematodes have produced viable eggs. [29]

8.3 Nematodes and crown rot

While all winter cereals host the crown rot fungus, yield loss due to infection varies with cereal type. The approximate order of increasing yield loss is cereal rye, oats, barley, bread wheat, triticale and durum wheat. [30]

Many trials concentrate on crown rot, and it is becoming more important to build a picture of the interaction of crown rot with other factors, especially in combination with *Pt* levels. As well as reducing yield, *Pt* reduces grain quality and Nitrogen Use Efficiency, and increases the severity of crown rot infections. [31]

There have been numerous field trials since 2007 evaluating the impact of crown rot on a range of winter-cereal crop types and varieties. This work has greatly improved the understanding of crown rot impact 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 that indicated *P. thornei* was having a frequent and large impact on wheat variety yield. [32]

Where Pt combines with high levels of crown rot (a common scenario), yield losses can be exacerbated if varieties are susceptible to Pt. Instead of a 10% yield loss from

29 G Hollaway (1996) Cereal root diseases. Agriculture Victoria, January 1996, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

30 GRDC (2016) Tips and Tactics: Crown rot in winter cereals—Southern region.

31 Dixon T. (2013). Balancing Crown rot and Nematodes in wheat. Ground Cover Issue 104: May – June 2013. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-104-May-June-2013/Balancing-crown-rot-and-nematodes-in-wheat

32 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

Pt in a susceptible variety, it could be 30–50% if crown rot is combined with a Pt-intolerant variety (Photo 7).

The research has also shown that not only does Pt cause high yield loss in susceptible varieties, but Pt numbers can increase much faster than in an area in which tolerant varieties are growing. These increased Pt numbers can lead to even greater damage in future crops. [33]

Photo 7: *Grass plant showing both parasitic nematode damage to roots and crown rot in above ground tissues.*

Source: NCSU)

There is increasing evidence for the enhancing effect of nematodes on levels of crown rot, which durum is very susceptible to. An extensive NSW farm survey conducted by Industry and Investment NSW exploring the effect of crown rot on wheat varieties including durum also highlighted the extensive level of nematodes, especially *P. thornei*, throughout the cropping belt. The researchers concluded that where *P. thornei* combines with high levels of crown rot (a common scenario), yield losses can be exacerbated if varieties are susceptible to *P. thornei*. Instead of a 10% yield loss from *P. thornei* in a susceptible variety it could be 30–50% if crown rot is combined with a *P. thornei*-intolerant variety. These trials were designed to evaluate the impact of crown rot on variety yield and quality. However, results strongly suggest that *P. thornei* is also having a significant impact on yield performance. The results do not compare the actual levels of yield loss due to the two diseases but indicate there is a greater range in variety *P. thornei* tolerance than currently exists for crown rot tolerance. Put simply, variety choice appears a more valuable tool when under *P. thornei* pressure than as a tool for crown rot management. [34]

8.3.1 Management

Variety choice is the key management option when it comes to managing Pt risk. However, when it comes to crown rot management, although varieties have some impact, rotation and stubble management are by far our most important management tools. RLN, especially Pt, need to be taken far more seriously and better factored into crop rotation considerations as well as variety choice. [35]

MORE INFORMATION

The additive yield impact of root lesion nematode and crown rot

VIDEOS

WATCH: GCTV9: Crown rot and root-lesion nematode.

33 B Freebairn (2011) Nematodes and crown rot: a costly union. Ground Cover Issue 91, March-April 2011. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union

34 GRDC (2010) The additive yield impact of root-lesion nematode and crown rot? GRDC update papers. Grains Research and Development Corporation, September 2010, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/THE-ADDITIVE-YIELD-IMPACT-OF-ROOT-LESION-NEMATODE-AND-CROWN-ROT

35 B Freebairn (2011) Nematodes and crown rot: a costly union. Ground Cover Issue 91, March-April 2011, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union

Soil testing

PreDictaB

Cereal root diseases cost grain growers in excess of $200 million a year in lost production. Much of this can be prevented.

PreDicta B (B = broadacre) is a DNA-based soil testing service that identifies which soil-borne pathogens pose a significant risk to broadacre crops prior to seeding (Photo 8).

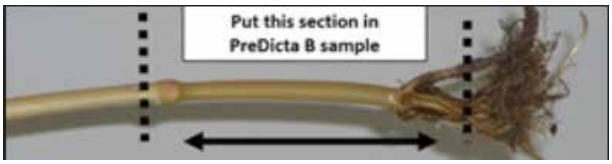


Photo 8: *Correct sampling strategy.*

Source: GRDC

PreDicta B includes tests for:

- Take-all (*Gaeumannomyces graminis var tritici (Ggt)* and *G. graminis var avenae (Gga)*).
- Rhizoctonia barepatch (*Rhizoctonia solani AG8*).
- Crown rot (*Fusarium pseudograminearum and F. culmorum*).
- Blackspot of peas (*Mycosphaerella pinodes, Phoma medicaginis var pinodella* and *Phoma koolunga*).

Access PreDicta B testing service

You can access PreDicta B diagnostic testing services through a SARDI accredited agronomist. They will interpret the results and give you advice on management options to reduce your risk of yield loss.

SARDI processes PreDicta B samples weekly between February and mid-May (prior to crops being sown) every year.

These timeframes help SARDI assist you with your cropping program.

PreDicta B is not intended for in-crop diagnosis. See SARDI's crop diagnostic webpage for other services.

Varietal choice

Crop rotation and variety choice are the important factors in protection against both diseases. Choosing a variety solely on crown rot resistance is not critical, especially if appropriate management techniques have been carried out, but choice of variety is crucial when it comes to *Pt* tolerance.

Further research into varietal tolerance to crown rot and nematodes has revealed that choosing a variety is difficult. Determining the relative tolerance of varieties to crown rot is complex as it can be significantly influenced by background inoculum levels, RLN populations, differential variety tolerance to *Pn* versus *Pt* and varietal interaction with the expression of crown rot. Other soil-borne pathogens such as *Bipolaris sorokiniana*, which causes common root rot, also need to be accounted for in the interaction between crown rot and varieties. Starting soil water, in-crop rainfall, relative biomass production, sowing date and resulting variety phenology in respect to moisture and/or temperature stress during grain-fill can all differentially influence the expression of crown rot in different varieties. [36]

36 T Dixon (2013) Balancing Crown rot and Nematodes in wheat. Ground Cover Issue 104: May—June 2013. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-104-May-June-2013/Balancing-crown-rot-and-nematodes-in-wheat

Diseases

Key messages:

- Durum has mixed resistance to common cereal diseases.
- Durum is highly susceptible to crown rot.
- Genetic research and strategic breeding is improving durum resistance to major diseases. Annually published disease guides should be consulted for rating changes
- Key strategies for management are:
- green bridge management
- utilising resistant varieties
- seed and/or fertiliser treatments
- crop rotation
- active monitoring of crops with a view to fungicide applications if required.

9.1 Diseases in durum

Disease problems change over time as seasons vary and farm management practices evolve. More recently there has been a rapid change in rust strains that has seriously restricted the choice of varieties suitable for cultivation. These factors make it more apparent than ever that the cereal industry needs to be vigilant in its control of cereal diseases and that disease control requires integrated approaches that take into account fungal pathology, farm management systems and plant breeding. Strong promotion of Minimum Disease Resistance Standards and less reliance on fungicides are also needed as part of this approach. Without greater care there is potential in future years for a massive increase in inoculum loads that will in turn increase disease problems. With strong advocacy and effective extension activities, plant pathologists with expertise across these areas can make a big difference to the sustainability of cereal farming.

Fungal diseases of cereals are sporadic in occurrence and severity. This variation comes about from changes in seasonal conditions, farm management practices, varieties grown and pathotypes of the fungi. Where conditions are favourable any one pathogen can lead to severe losses over several years and growers are required to make significant changes to their varieties, rotations or other practices to avoid damage. In other situations a disease may cause significant losses in one year then not recur for some time. Many of these situations can be avoided through careful judgement of risks, and active promotion and implementation of effective strategies. [1]

1 GRDC (2004) Control of cereal fungal diseases. Final reports DAS336. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAS336

Table 1: *Resistance of major durum varieties to common cereal diseases in South Australia for 2016.*

Durum wheat variety	Rust			*Septoria tritici* blotch	Cereal cyst nematode resistance	Yellow leaf spot	Powdery mildew	Root lesion nematodes		Crown rot	Common root rot	Flag smut	Black point
	Stem	Stripe	Leaf					*P. neglectus*	*P. thornei*				
Aurora(Ɒ	RMR	RMR	R	MS	MS	MRMS	MR	MS	RMR	VS	MRMS	R	MS
Caparoi(Ɒ	RMR	MR	RMR	RMR	MS	MR	-	MSS	MR	VS	MS	R	MSS
Hyperno(Ɒ	RMR	MR	R	MRMS	MS	MRMS	MR	MS	RMR	SVS	MS	R	MS
Saintly(Ɒ	MR	MR	MRMS	S	MS	MRMS	MSS	MS	MR	VS	MS	R	MS
Tjilkuri(Ɒ	MR	MR	R	MSS	MS	MRMS	MRMS	MS	MR	VS	MS	R	MSS

Abbreviations					
R	Resistant	MR	Moderately resistant	MS	Moderately susceptible
S	Susceptible	VS	Very susceptible	MI	Moderately intolerant
I	Intolerant	-	Uncertain		

Source: Primary Industries and Regions South Australia

MORE INFORMATION

Cereal variety disease guide

Table 1 lists the resistance of major durum varieties to common diseases in South Australia (SA) during the 2016 season. A recent South Australian cereal variety disease guide reported that the most concerning developments in the 2015 season were an increase in Septoria tritici blotch and eyespot in wheat crops across a wide area of the state. Take-all affected many wheat crops along SA's far west coast and central Eyre Peninsula particularly in calcareous soils and in paddocks where there was a history of intensive wheat and grass weeds combined with reduced stubble breakdown. [2]

9.1.1 Crown rot

Key points:

- No in-crop control is available for crown rot.
- This fungal disease is hosted by all winter cereals and many grassy weeds.
- Crown rot survives for many years in infected plant residues and infection can occur when plants come in close contact with those residues.
- High cereal intensity and inclusion of durum wheat in cropping programs are factors which increase crown rot levels.
- Major yield losses occur when disease levels are high and there is moisture stress during grain fill. In these circumstances yield loss can be up to 90% in durum.
- Crown rot can cause increased screenings in durum. [3]

Of all the cereal diseases, crown rot has the greatest impact on durum yield. Crown rot causes crop losses in Australia estimated at $79 million, or $6.63 per hectare, per year. [4] Many growers stopped growing durum because of the high risk of crown rot. Durum wheat remains the most susceptible of the winter cereal crops to crown rot infection and yield loss.

Bread wheat yield losses can be up to 55% at high inoculum levels. Losses in durum can reached up to 90%. [5] Crown rot is caused by fungal *Fusarium spp.* [6] The

2 H Wallwork (2016) Cereal variety disease guide 2016. Primary Industries and Regions South Australia, February 2016, http://pir.sa.gov.au/__data/assets/pdf_file/0010/276841/Cereal_Variety_Disease_Guide_2016_web.pdf

3 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

4 R Bowman (2012) Durum to partially resist crown rot. Ground Cover Issue 96. Grains Research and Development Corporation, January 2012, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-96-January-February-2012/Durum-to-partially-resist-crown-rot

5 GRDC (2014) Managing crown rot. Grains Research and Development Corporation, June 2014, https://grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

6 GRDC (2006) Crown rot management in durum and bread wheats for the southern region. Final report DAS00032. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAS00032

fungus survives over summer on infected plant residues (crown and base of stem) and can persist for at least three years depending on rainfall. [7] As infected residues decompose, inoculum levels reduce. This means that where decomposition rates are low, crown rot inoculum can survive for several years. [8]

Crown rot infection occurs when infected residues come into contact with growing cereals e.g. where stubble has been knocked down by machinery or heavy grazing. [9] Even minute pieces of residue can cause infection and a paddock with little visible stubble may still have a crown rot risk. Infection occurs in the sub-crown internode, crown and/or outer leaf sheaths at the tiller bases. The fungus spreads up the stem during the season, with most inoculum being found near the base of the plant. [10]

Figure 1 demonstrates the increased yield loss, especially in durum, when exposed to increased levels of crown rot at sowing.

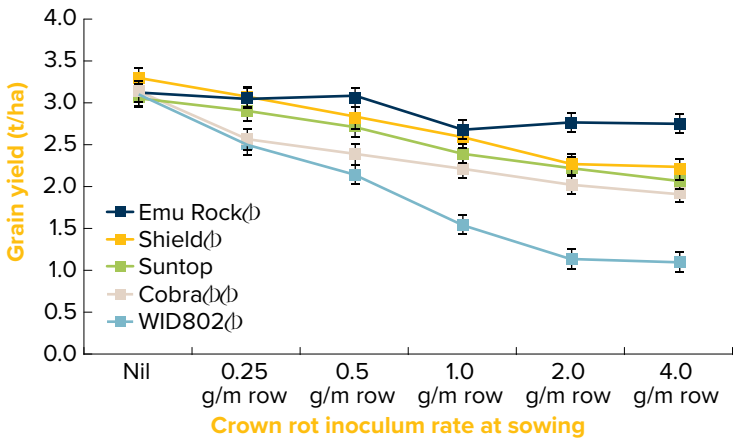


Figure 1: *Effect of increasing crown rot inoculum levels at sowing on the grain yield (t/ha) of one durum wheat (WID802) and four bread wheat cultivars grown at Dooen during 2015.*

Source: Grains Research and Development Corporation

Where crown rot species are found in southern Australia

High levels of crown rot have been detected in soil samples across all southern states. *Fusarium* species associated with crown rot were isolated and identified from 409 wheat, barley or durum wheat crops from the eastern Australian grain belt between 1996 and 1999:

- *F. pseudograminearum* was the most common species in Victoria and SA, but *F. culmorum* was also frequently found.
- *F. culmorum* accounted for more than 70% of isolates from the Victorian high rainfall (>500 mm) region and the south-east region of SA.
- *F. culmorum* comprised 18% of isolates from the Victorian medium rainfall (350–500 mm) region, and 7% of isolates from each of the Victorian low rainfall region and the Mid-North region of SA.

7 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

8 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

9 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

10 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

- The proportion of *F. culmorum* among isolates of *Fusarium* from districts in Victoria and SA was strongly correlated with climatic conditions around the end of the growing season, especially with rainfall in November.
- *F. avenaceum*, *F. crookwellense* and *F. graminearum* were found very infrequently. [11]

9.1.2 Varietal resistance

Resistance is only possible in healthy, growing plants. Once a plant is stressed or starts to dry off at the end of grain fill, the crown rot fungus will take hold regardless of its resistance rating. [12]

See Table 1 in the section 1.1 Diseases in durum for varietal resistance to crown rot in SA and Victoria.

9.1.3 Damage caused by disease

Crown rot often causes whiteheads to occur which mature early and contain shrivelled grain or no grain. The impact of a bad crown rot season can make or break a crop, with bread wheat yield losses of up to 55%, and durum yield losses of up to 90% possible at high inoculum levels. [13] Because crown rot can survive in the soil for years, damage to crops can be felt over long periods.

9.1.4 Symptoms

The distinctive symptom of crown rot is the presence of whiteheads in the crop at early grainfill (Photo 1). These heads mature early and contain shrivelled grain or no grain. Whiteheads caused by crown rot are usually scattered through the crop and do not appear in distinct patches as seen with the root disease take-all. The other, and more reliable, symptom of crown rot is browning of the stem bases. [14] A brown stem base is the most reliable indicator of crown rot and this symptom becomes more pronounced from mid to late grainfill through to harvest (Photo 2). To see the honey/dark brown colour more easily the leaf sheaths should be pulled back. This symptom may not appear on all stems. [15]

11 D Backhouse, AA Abubakar, LW Burgess, JI Dennisc, GJ Hollaway, GB Wildermuth, H Wallwork, FJ Henry 2004) Survey of *Fusarium* species associated with crown rot of wheat and barley in eastern Australia. Australasian Plant Pathology 33, 255–261, doi:10.1071/AP04010

12 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

13 GRDC (2014) Managing crown rot. Grains Research and Development Corporation, June 2014, https://grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

14 G Hollaway, M McLean, J Fanning (2016) Cereal disease management in Victoria 2016. GRDC update papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-disease-management-in-Victoria-2016

15 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

Photo 1: *Whiteheads (left) caused by crown rot compared to healthy wheat (right).*

Source: Grains Research and Development Corporation

Photo 2: *Healthy tillers (left) and severe basal or stem browning caused by crown rot (right).*

Source: Grains Research and Development Corporation

9.1.5 Conditions favouring development

Conditions which favour crown rot development are good growing conditions at the start of the season followed by stress after head emergence. Inoculum levels have built up in many areas of SA over recent years, due to the high number of dry springs experienced, more intensive cereal rotations and stubble retention practices. [16]

Infection is favoured by moderate soil moisture at any time during the season. The expression of whiteheads is favoured by moisture stress during grainfill and there is

16 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

VIDEOS

WATCH: GCTV9: Crown rot and root lesion nematodes.

a direct relationship with yield loss. Increases in moisture stress will increase crown rot severity; e.g. increased seeding rate can lead to more severe moisture stress and crown rot consequences. [17] The expression of whiteheads in crown rot infected tillers can also be more severe in zinc-deficient crops. [18]

Crown rot is favoured by the intensive cultivation of cereals and stubble retention practices which contribute to losses during seasons with below average spring rainfall. Whitehead expression is more common in seasons with a dry spring. [19] The presence of root-lesion nematodes exacerbates the effects of crown rot, reducing the ability of the crop to extract soil water to deal with crown rot infection. [20]

FAQ

9.1.6 Management of disease

For durum wheat, crown rot is by far the largest factor limiting expansion. Many growers gave up on durum because of the high risk of crown rot. The remaining growers are mostly managing it with longer rotations. [21]

Important tips for managing crown rot:

- Test paddocks for crown rot levels using PredictaB.
- If sowing in paddocks where crown rot is present, ensure that these paddock are low in infected stubbles, by use of longer rotations.
- Try to reduce late moisture stress by early sowing, not using high seeding rates, managing nitrogen (N) according to crop needs and not applying too much N upfront. [22]

Trigger points

Table 3 lists trigger points for making sowing decisions based on PreDicta B risk ratings for crown rot. Durum should only be sown in paddocks known to have a low crown rot level. [23]

Table 2: *Trigger points for making sowing decisions based on PreDicta B risk ratings for crown rot.*

PreDicta B risk rating	Action
Low	Unlikely to be an issue in the short term
Medium	Do not sow durum, avoid bread wheat if possible
High	Rotate to at least two non-cereal crops

Source: Primary Industries and Regions South Australia

See Section 1: Paddock selection and preparation for more information on soil testing and PreDicta B.

Paddocks at high risk should be sampled and tested using a PreDicta B test and the results taken into account when making sowing decisions. Autumn burning will only reduce inoculum levels by 40 to 50% as plant parts below the ground will be protected and host inoculum (Table 4). [24]

17 H Wallwork (2016) pers. comms.

18 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

19 G Hollaway, M McLean, J Fanning (2016) Cereal disease management in Victoria 2016. GRDC update papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-disease-management-in-Victoria-2016

20 GRDC (2014) Managing crown rot. Grains Research and Development Corporation, June 2014, https://grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

21 H Wallwork (2016) pers. comms.

22 H Wallwork (2016) pers. comms.

23 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

24 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

Table 3: *Crown rot yield loss categories using PreDicta B soil tests.*

	Durum wheat	
Risk rating	**Log (DNA)**	**% Yield loss**
Below detection limit	<0.6	0–2
Low	0.6–1.4	0–5
Medium	1.4–2.0	10–30
High	>2.0	20–80

Source: Primary Industries and Regions South Australia

If durum must be sown but there is a risk of yield loss from crown rot:

- Match N application to stored soil moisture and potential yield.
- Limit early N applications to avoid excessive early crop growth.
- Ensure zinc nutrition is adequate.
- Sow on the inter-row if this option is available. [25]

Inspections of stems for browning is best performed from mid to late grainfill through to harvest. To see the browning, leaf sheaths should be pulled back and in some cases the pink of the causal fungus may be observed. Collect representative plant samples from the paddock by walking in a large 'W' pattern, collecting five plants at 10 different locations (Figure 4). Examine each plant for basal browning, record what percentage shows the symptom and then put in place appropriate measures for next year. [26]

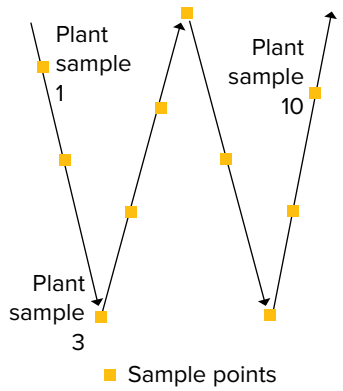


Figure 2: *'W' pattern for plant sampling in paddock.*

Source: Grains Research and Development Corporation

Crown rot must be controlled prior to sowing as there is no in-crop control available. Inspection of previous cereals for the presence of crown rot symptoms provides an indication of potential risk from crown rot. [27]

Choosing paddocks with low crown rot risk is essential for growing a successful durum wheat crop. Soil sampling methods and risk categories for DNA-based testing for crown rot mean growers can choose the best paddocks for growing durum. Soil sampling to assess DNA levels of crown rot prior to sowing is a useful paddock

25 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

26 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

27 G Hollaway, M McLean, J Fanning (2016) Cereal disease management in Victoria 2016. GRDC update papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-disease-management-in-Victoria-2016

management tool. Soil sampling is a reliable method for making this assessment and may be the only reliable option in some instances, e.g. where cereal stubble is no longer present for visual assessment of crown rot levels. Stubble sampling for crown rot using DNA technology is a useful research tool. Where it is intended to sow between old cereal rows, a soil DNA test should be used to assess crown rot risk as the between-row levels of crown rot may still be high (e.g. where there are significant residues from grassy weeds or where the cereal stubble has been moved around by grazing). The more cereals there are in the rotation the greater the risk of losses to crown rot, as all cereals will build up crown rot.

Closed canopy break crops and fallow are most effective at reducing crown rot. Closed canopy crops such as canola and vetch are more effective than medic or peas at reducing crown rot levels in the year they are sown. Long fallow is also effective at reducing crown rot levels, but is less desirable financially. Manage grassy weeds during breaks from cereals, as brome grass, ryegrass, barley grass and wild oats all carry significant levels of crown rot. Where crown rot levels are high, at least a two-year rotational break is needed before it will be safe to sow durum. Break crops will continue to be the main management tool for crown rot, but will need to be combined with other management options to achieve their full benefit. The research challenge is to reduce the break period to one year, even where crown rot levels are high.

Burning is unreliable in reducing crown rot. Hay making, straw baling, cultivation and burning will generally not reduce high crown rot to low levels in the short term but could assist in long term maintenance of low crown rot levels. The agronomic implications (reduced organic matter and soil cover) of these operations need to be considered when employing them for crown rot management. [28]

Management options which decrease crown rot levels:

- Where crown rot levels are high, at least a two-year rotational break will be needed before it is safe to sow durum:
- Good rainfall increases the effectiveness of the break, because microbial decomposition of the cereal residues harbouring the pathogen is greater in moist conditions.
- For break crops, early canopy closure and warm, damp conditions under the canopy will result in the fastest decomposition of crown rot-infected residues. [29]
- Canola, fallow and vetch are more effective than medic or peas at reducing soil crown rot levels (Figure 3).
- Soil crown rot levels take longer to decrease after triticale than after other cereal crops.
- A grass-free pasture can reduce levels of crown rot even under low rainfall conditions.
- Reducing levels of crown rot in low rainfall farming systems such as Eyre Peninsula is likely to be difficult due to limited options for grass-free breaks from cereals.
- Trace elements (zinc, copper, manganese) appear to play a minor role in managing the effects of crown rot in-season. [30]

28 GRDC (2006) Crown rot management in durum and bread wheats for the southern region. Final report DAS00032. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAS00032

29 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

30 GRDC (2006) Crown rot management in durum and bread wheats for the southern region. Final report DAS00032. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAS00032

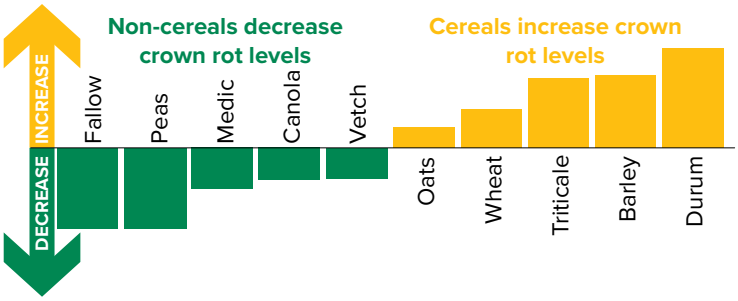


Figure 3: *Rotation effects on crown rot levels in the soil in the following year—a summary based on five trials conducted in SA and Victoria.*

Source: Grains Research and Development Corporation

Is sowing time, row spacing or plant population a viable management tool to minimise losses from crown rot?

Two crown rot trials conducted in north-west New South Wales in 2012 compared the effects of time of sowing and row spacing on losses due to crown rot in bread wheat, barley and durum varieties. The key findings were:

- In durum, low plant populations coupled with an early sowing time reduced yield loss to crown rot by 50% compared to a later sowing time with a higher plant population (25% yield loss to crown rot).
- Yield losses from crown rot in durum were 15-30%, while losses were 7-15% for wheat and minimal for barley (<5%). The losses for durum reinforce the need to avoid growing durum where there is a risk of crown rot.
- Variety selection had greater potential to affect yields than losses incurred from crown rot infection.
- In this trial using wider row spacing (500 mm) actually increased soil water use in the 0–60 cm zone and therefore did not reduce yield loss from crown rot.
- Infection with crown rot significantly reduced soil water use during the last three weeks of grainfill. [31]

Seven commercial wheat trials in 2006 showed inter-row sowing decreased both crown rot severity (average 53%) and incidence (average 48%) compared to sowing on the previous year's cereal rows. The positive effect of inter-row sowing is most beneficial when inoculum levels are low, but is still valuable where inoculum levels are severe. An average benefit of 101 kg/ha was recorded across the trials making inter-row a useful additional strategy but not a primary management tool for crown rot. Inter-row sowing will certainly not enable 'back to back' wheat production where crown rot levels are already high. [32]

Under high crown rot pressure, yield losses in durum cannot be managed by manipulating the plant population at sowing. Given the extreme susceptibility of durum wheat to crown rot, it remains critical to target durum production only in paddocks known to have low levels of inoculum. [33]

31 M Gardner, SSimpfendorfer (2013) Is sowing time, row spacing or plant population a viable management tool to minimise losses from crown rot? GRDC update papers. Grains Research and Development Corporation, March 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Is-sowing-time-row-spacing-or-plant-population-a-viable-management-tool-for-crown-rot

32 GRDC (2014) Managing crown rot. Grains Research and Development Corporation, June 2014, https://grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

33 GRDC (2010) Impact of plant population on crown rot in durum wheat. GRDC update papers. Grains Research and Development Corporation, September 2010, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/IMPACT-OF-PLANT-POPULATION-ON-CROWN-ROT-IN-DURUM-WHEAT

Stubble management for crown rot

Stubble management practices such as spreading,slashing and cultivation can increase the rate of stubble decomposition but can also spread the infected residues across the paddock. Additionally, cultivation can exacerbate crown rot by reducing soil moisture. Where there is no moisture or adequate time to enable stubble breakdown, these practices can increase infection rates in the next winter cereal crop. Grazing stubble can also spread inoculum. [34]

Crown rot infection occurs when infected residues come into contact with growing cereals, so where stubble has been knocked down by machinery or heavy grazing, stubble displacers ahead of the sowing tines/disks may be advantageous. [35]

In-crop fungicides and timing

There are no fungicide options for the control of the crown rot. [36]

Resistant disease control options

New sources of crown rot resistance have been identified, in wild relatives of durum wheat. Development of adapted germplasm has commenced. In time (possibly within a decade) this should lead to the release of varieties that are not highly susceptible to this disease. This may allow durum crops to be grown in closer rotation. [37]

VIDEOS

WATCH: What's in the crown rot breeding pipeline?

9.1.7 Advances against crown rot

If resistance to crown rot can be improved, then the area sown to durum could rise very significantly both in existing areas and in areas where growers have discontinued production. [38]

Partial resistance in commercial durum varieties (similar to Sunco bread wheat) will be a significant contributor to managing crown rot. Improved resistance should be attainable in the next five to 10 years. [39]

Screening activities to date have failed to identify even moderately susceptible lines of durum. In contrast, partial resistance to crown rot has been identified in a number of bread wheat lines, including 2-49 and Sunco. A study from 2013 describes the successful introgression of partial crown rot resistance from each of these two wheat lines. Durum backcross populations had crown rot scores similar to 2-49. Progeny of these backcross populations included lines with field based resistance to crown rot superior to that of the parent wheat. [40]

Partial resistance will need to be coupled with an integrated approach to managing the disease. There is no total resistance to crown rot fungus infection in durum or other cereals. The genes involved provide partial resistance, which appears to slow the rate of it spreading through tissue. [41]

Durum lines have to be well adapted, as well as have resistance, because crown rot is favoured by moisture stress and durum that is not well adapted suffers greater moisture stress and resistance can be hidden due to their lack of adaptation. [42]

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34 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

35 PIRSA (2014) Soil-borne disease risks emerge in 2014. Primary Industries and Regions South Australia, April 2014, http://pir.sa.gov.au/alerts_news_events/news/archives/sardi_archive/soilborne_disease_risks_emerge_in_2014

36 GRDC (2009) Crown rot in cereals fact sheet. Grains Research and Development Corporation, May 2009, http://www.grdc.com.au/GRDC-FS-CrownRotCerealsSW

37 GRDC (2004) Control of cereal fungal diseases. Final reports DAS336. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAS336

38 H Wallwork (2016) pers. comms.

39 GRDC (2006) Crown rot management in durum and bread wheats for the southern region. Final report DAS00032. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAS00032

40 A Martin, S Simpfendorfer, RA Hare, MW Sutherland (2013) Introgression of hexaploid sources of crown rot resistance into durum wheat. Euphytica, 192(3), 463–470, doi:10.1007/s10681-013-0890-6

41 R Bowman (2012) Durum to partially resist crown rot. Ground Cover Issue 96. Grains Research and Development Corporation, January 2012, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-96-January-February-2012/Durum-to-partially-resist-crown-rot

42 H Wallwork (2016) pers. comms.

Zinc to help buffer effects of crown rot

IN FOCUS

Response of durum wheat to different levels of zinc and *Fusarium pseudograminearum*

Durum wheat (*Triticum turgidum* ssp. *durum*) is susceptible to *Fusarium pseudograminearum* and sensitive to zinc (Zn) deficiency in Australian soils. However, little is known about the interaction between these two potentially yield-limiting factors, especially for Australian durum varieties. The critical Zn concentration (concentration of Zn in the plant when there is a 10% reduction in yield) and degree of susceptibility to *F. pseudograminearum* was therefore determined for five Australian durum varieties (Yawa(D), Hyperno(D), Tjilkuri(D), WID802(D), UAD1153303). Critical Zn concentration averaged 24.6 mg/kg for all durum varieties but differed for the individual varieties (mg/kg: Yawa(D), 21.7; Hyperno(D), 22.7; Tjilkuri(D), 24.1; WID802(D), 24.8; UAD1153303, 28.7). Zinc efficiency also varied amongst genotypes (39–52%). However, Zn utilisation was similar amongst genotypes under Zn-deficient or Zn-sufficient conditions (0.51–0.59 and 0.017–0.022 g DM/µg Zn, respectively). All varieties were susceptible to *F. pseudograminearum* but the development of symptoms and detrimental effect on shoot biomass and grain yield were significantly greater in Tjilkuri(D). Though crown rot symptoms may still be present, the supply of adequate Zn in the soil helped to maintain biomass and grain yield in all durum varieties. However, the extent to which durum varieties were protected from plant growth penalties due to crown rot by Zn treatment was genotype-dependent. [43]

Funding for field trials in southern Australia

The Southern Australia Durum Growers Association received funding from the South Australian Grain Industry Trust in 2016 to undertake the project *Agronomic evaluation of durum wheats for crown rot resistance*. The three-year project will compare varieties and breeding lines without crown rot infection and with infection induced by different levels of crown rot inoculum applied at sowing. The trials will be conducted in the Lower North and South East regions of SA. The effects of sowing dates and/or seeding rates on disease pressure will also be explored. [44]

9.1.8 Common root rot

Common root rot, caused by the fungus *Bipolaris sorokiniana*, is often found in association with crown rot. Symptoms are a dark brown to black discoloration of whole or part of the sub-crown internode. Severely affected plants are stunted, have fewer tillers and produce smaller heads. Rotation to non-host break crops is essential to the successful management of both of these diseases. See Section 2.1 for varietal details.

43 MS Al-Fahdawi, JA Able, M Evans, AJ Able (2014). Response of durum wheat to different levels of zinc and *Fusarium pseudograminearum*. Crop and Pasture Science, 65(1), 61–73, http://dx.doi.org/10.1071/CP13306

44 Southern Australia Durum Growers Association (2016) Successful grant application. Southern Australia Durum Growers Association, June 2016, http://durumgrowerssa.org.au/news-flash-successful-grant-application/

9.2 Stripe, leaf and stem rust

Durums are generally moderately resistant to leaf stem and stripe rust in the Southern Region. They may offer a good alternative to hard wheat where rust is a risk.

Durum varieties differ little in resistance to rusts. Cereal rusts have the potential to cause heavy yield losses in some situations, depending on susceptibility of the variety sown (Table 5). [45] There is potential for up to 10% yield loss in durums in some situations as all varieties range from R-MR.

9.2.1 Varietal resistance

See Table 1 and Table 2 in section 1.1 Diseases in durum for varietal resistance to stripe, leaf and stem rust in the Southern region.

Kamilaroi(D), Yallaroi(D), Wollaroi(D) and EGA Bellaroi(D) are fully resistant to all existing field strains of stem rust. While stem rust infection is not expected, a new virulent strain may occur. Kamilaroi(D), Yallaroi(D), Wollaroi(D) and EGA Bellaroi(D) possess slow rusting resistance to all field strains of leaf rust. A small level of infection may be evident as the plant approaches maturity; however, this disease level will not affect yield. The current durum varieties all express adequate resistance to field strains of stripe rust at present. [46]

9.2.2 Symptoms

Stripe rust

Stripe rust is easiest to identify in the morning. Examine the leaves, especially the older leaves low in the canopy, and look for yellow stripes of pustules. Pustules are raised above the leaf surface and can be easily wiped off onto a white cloth or tissue leaving a yellow stain (Photo 3). Also, watch for hot spots in the crop: hot spots are often 1–10 metres in diameter, and are generally well developed just before the disease becomes widespread in the crop. [47]

Photo 3: *Stripe rust on a moderately susceptible to susceptible wheat variety.*

Source: Agriculture Victoria

Stem rust

Stem rust is characterised by reddish-brown, powdery, oblong pustules. The pustules have a characteristic torn margin that can occur on both sides of the leaves, on the stems and the glumes. Stem rust spores are much darker in colour than leaf rust

45 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

46 R Hare (2006) Agronomy of the durum wheats Kamilaroi(D), Yallaroi(D), Wollaroi(D) and EGA Bellaroi(D). Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

47 G Hollaway (2008) Stripe rust of wheat. Agriculture Victoria, February 2008, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/stripe-rust-of-wheat

spores, which are light brown and don't have torn margins (Photo 4). As the plant matures, the pustules produce black spores known as teliospores. They occur mainly on the leaf sheaths and stem. [48]

Photo 4: *Symptoms of stem rust on wheat (left) and symptoms of leaf rust on wheat (right).*

Source: Agriculture Victoria

9.2.3 Conditions favouring development

In seasons with summer or early autumn rain, germination of volunteer cereals will increase the risk of stripe, leaf and stem rust. Control of volunteers by grazing or spraying is needed to prevent build up of inoculum. [49]

Stripe rust

Stripe rust is caused by *Puccinia striiformis* f.sp. *tritici*. The fungus is dispersed as wind-blown spores which produce new infections. Conditions suitable for epidemic development occur from April to December in Victoria, and stripe rust can be expected in crops by September in most years. The fungus requires temperatures of less than 18°C (optimum 6–12°C) with a minimum of three hours of leaf-wetness (for example, dew) for new infections to occur. Once an infection is established the fungus can survive short periods of temperatures higher than 40°C. Sufficient rust can survive the summer on volunteer or self-sown wheat plants resulting in a new epidemic to develop in the following season. Only one infected leaf per 30 ha of regrowth needs to survive the summer to produce severe epidemics. Stripe rust can also infect the developing head, reducing grain number and size. [50]

48 G Hollaway (2005) Stem rust of wheat. Agriculture Victoria, February 2008, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/stem-rust-of-wheat

49 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

50 G Hollaway (2008) Stripe rust of wheat. Agriculture Victoria, February 2008, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/stripe-rust-of-wheat

Stem rust

Stem rust (caused by the fungus *Puccinia graminis*) can only survive from one season to the next on a living host. It does not survive on stubble, seed or soil. The most important hosts are susceptible wheat, but it can also survive on barley, triticale, and some grasses. Carry over on wheat from one season to the next is greatest during wet summers/autumns. Rust spores are wind-blown and can be spread over large areas in a short time. Wet conditions and temperatures of approximately 15–30°C favour the establishment of stem rust within crops. Stem rust usually becomes evident later in the season than stripe rust. [51]

Leaf rust

Leaf rust is caused by the fungus Puccinia triticina. Leaf rust, like other cereal rusts, requires a living host to survive from one season to the next. The most important host for rusts in Australia are susceptible volunteer wheat plants growing during the summer/autumn. Rust cannot carry over from one season to the next on seed, stubble or in soil.

Wheat varieties susceptible to leaf rust enable inoculum levels to build up on volunteers during the summer and autumn. This can be a problem in seasons following wet summers that favour the growth of self-sown wheat. Plants that become heavily infected with rust in the autumn provide a source of rust for the new season's wheat crop. If these conditions are followed by a mild winter and a warm wet spring, then the chances of a leaf rust epidemic are high. Therefore, the chances of a rust epidemic are greatest following a wet summer.

In Australia, due to the absence of the alternate host, leaf rust reproduces asexually. This reduces the variability of the rusts in the field and therefore increases the likelihood that resistant varieties will be effective for a long period of time.

Rust spores are wind-blown and can be spread over large areas in a short time. The establishment of leaf rust epidemics within a crop is favoured by wet conditions and temperatures of in the range of 15-22°C. [52]

9.2.4 Management of rusts

Sowing susceptible and very susceptible varieties should be avoided. Durum varieties are generally moderately resistant or better and rust control would not be warranted but in severe seasons or if early infection is a risk some control may be needed.

In-crop fungicides and timing

Stripe rust control

Good upfront control of stripe rust by seed or in-furrow treatments can be achieved until stem elongation (GS30). In some environments control can be achieved through until flag leaf emergence.

Moderately resistant or resistant varieties: Level of resistance at adult stage is adequate to protect crop. Seedling infection may still require control.

Moderately susceptible and susceptible varieties: Upfront disease control with Jockey® or Impact® is better in seasons with early breaks (green bridge) and short seasons. Foliar sprays will be beneficial with moderately resistant to moderately susceptible or lower resistance. While unlikely, as durums generally have good late season resistance to all rusts, situations may occur when growers need to apply cheaper fungicide first at GS30-39 and better fungicide later at GS41 to protect the flag leaf.

51 G Hollaway (2005) Stem rust of wheat. Agriculture Victoria, February 2008, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/stem-rust-of-wheat

52 G Hollaway (2014) Leaf rust of wheat. Agriculture Victoria, February 2008, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/leaf-rust-of-wheat

Trigger points for stripe rust control:

- Spray moderately susceptible and lower resistant varieties.
- At GS30 spray at the first sign of disease.
- At GS39 spray at 1% infection. [53]

Why do these growth stage timings work for stripe rust control?

Five to 10 years ago, it would have been common to make decisions on fungicide applications for stripe rust based on thresholds of infection; these thresholds varied from 1-5% plants infected. A problem soon became apparent to growers and advisers 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. Additionally, 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, control is poor, since 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 timings gave good control of the disease. These growth stage-based timings also gave growers the opportunity to plan disease management strategies for susceptible cultivars.

The primary reason that these timings work 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), since they have not emerged at this early stem elongation growth stage. Equally, a foliar fungicide applied at flag leaf (GS39) may protect the flag leaf but may be too late to protect flag-2, which emerged two to three weeks earlier. [54]

Yield loss to stripe rust at different growth stage timing of disease onset

Although growth stage timings of 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 6). This simple chart (whilst complicated by the presence of adult plant resistance which occurs in most durum varieties) remains a useful guide to potential yield loss with susceptible cultivars at different growth stages.

53 PIRSA. Managing crop diseases. Primary Industries and Regions South Australia, http://pir.sa.gov.au/__data/assets/word_doc/0006/241584/Managing_Crop_Diseases.doc

54 N Poole, J Hunt (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

Table 4: *Expected yield losses (%) due to stripe rust based on timing of disease onset.*

Disease onset		Yield loss due to stripe rust (%)			
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

(Source: GRDC

PODCAST

Disease management and crop canopies.

Note that Table 6 is based on the premise that yield loss to stripe rust is dependent on:

- the extent of stripe rust by early grain development; and
- the temperature during grainfill (responses in the table assume average temperatures; if hotter, the yield loss attributable to disease is less than expected).

Otherwise, the data illustrate that the earlier the disease infects the crop, irrespective of variety resistance rating, the greater the expected loss. The time of stripe rust disease onset not only influences the expected return from foliar fungicides, it also influences the timing of fungicide applications in order to create the greatest return. [55]

Stem rust control

Spaying for stem rust control can be economic at later growth stages than for other diseases, with 50% yield increases as late as GS71. Fungicide will prevent subsequent infection when stem rust severity is slight on the plant parts to be protected.

Trigger points for stem rust control:

- When infection found on leaf sheaths, spray at GS39–51.
- When flag leaf sheath is infected, spray GS45–51.
- When peduncle (stem to the ear) is infected, spray GS55–75
- Optimum single spray at ear emergence GS55–59

9.3 *Septoria tritici* blotch

Septoria tritici blotch (STB) also called *Septoria* leaf spot or speckled leaf blotch is a fungal disease caused by the fungus *Mycosphaerella graminicola* (asexual stage *Zymoseptoria tritici*, synonym *Septoria tritici*). It can disperse over large distances early in the year when airborne spores are produced on infected wheat stubble. Subsequent infection only spreads by rain splash within the crop leading to hotspots of disease leaves where initial infection levels were low. [56] STB is a stubble-borne foliar disease that is now the most important wheat disease in Victoria's high rainfall cropping zones. The increase in STB has been favoured by stubble retention, intensive wheat production, susceptible cultivars and favourable conditions (cool and moist) for disease. Also, strains of STB with reduced sensitivity (partial resistance) to common fungicides have been detected. [57]

55 N Poole (2011) Cereal growth stages and decision making for fungicide timing. GRDC update papers. Grains Research and Development Corporation, September 2011, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

56 M Evans, H Wallwork (2016) Cereal pathology watch list for 2016. GRDC update papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-pathology-watch-list-for-2016

57 G Hollaway (2007) *Septoria tritici* blotch of wheat. Agriculture Victoria, December 2007, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/septoria-tritici-blotch-of-wheat

The disease had been developing as a serious problem in the south-east of SA due to increased wheat cultivation with closer rotations, although dry springs helped to greatly suppress *Septoria* damage in the two seasons prior to 2015. In 2015 the disease was observed over a wide area throughout the mid and high rainfall regions of SA. It is apparent that the disease must have become established in one or more wheat crops between the Tothill and Bluff Ranges north-west of Eudunda during 2014 or earlier. As well as increased virulence on Mace, the recently identified *Septoria* population has increased virulence on other related varieties to the point that few of the commercial varieties can now be expected to escape infection if sown early in areas where inoculum is present. Growers should therefore now take greater care with this disease, especially when growing the most susceptible varieties in *Septoria*-prone areas. [58] While Australian durum varieties have only low to moderate resistance, growers need to consult a current cereal variety disease guide for individual variety resistance ratings. [59] See Table 1 which shows Caparoi as being resistant to moderately resistant while Saintly is susceptible.

Key points:

- Distinctive black fruiting bodies on leaf lesions are a good indicator for diagnosis of STB infection.
- Long periods of leaf moisture are required for disease development.
- Early sown crops and crops sown into wheat stubbles are most likely to be infected.
- Two gene mutations in STB detected by the NSW Department of Primary Industries indicate resistance to some fungicides.
- Adoption of an integrated disease management approach that includes crop rotation and, when necessary, applied fungicides, is the most effective management tool. [60]

9.3.1 Varietal resistance

See Table 1 in the section 9.1 Diseases in durum for varietal resistance to STB in the Southern Region.

9.3.2 Damage caused by *Septoria tritici* blotch

When susceptible and very susceptible varieties are grown, STB is likely to cause annual average losses of up to 20%, with much higher individual crop losses possible. [61]

9.3.3 Symptoms

The fungus causes pale grey to dark brown blotches on the leaves, and to a lesser extent stems and heads. The diagnostic feature of *Septoria tritici* blotch is the presence of black fruiting bodies (pycnidia) within the blotches (Photo 5). These tiny black spots give the blotches a characteristic speckled appearance. When the disease is severe, entire leaves may be affected by disease lesions (Photo 6).

58 M Evans, H Wallwork (2016) Cereal pathology watch list for 2016. GRDC update papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-pathology-watch-list-for-2016

59 GRDC (2014) *Septoria tritici* blotch fact sheet. Grains Research and Development Corporation, February 2014, http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat

60 GRDC (2014) *Septoria tritici* blotch fact sheet. Grains Research and Development Corporation, February 2014, http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat

61 G Hollaway (2007) *Septoria tritici* blotch of wheat. Agriculture Victoria, December 2007, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/septoria-tritici-blotch-of-wheat

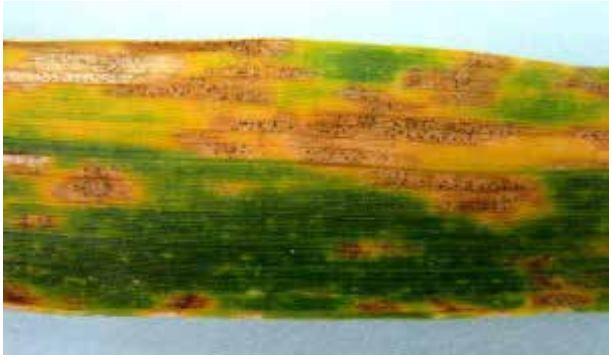


Photo 5: *Septoria tritici blotch causes pale grey to dark brown blotches on leaves; the presence of black fruiting bodies within the blotches is a diagnostic feature of the disease.*

Source: Grains Research and Development Corporation

Photo 6: *In severe cases of Septoria tritici blotch, entire leaves may be affected by disease lesions and the disease can cause complete death of leaves.*

Source: Agriculture Victoria

In the absence of the black fruiting bodies, which are visible to the naked eye, similar blotching symptoms may be caused by yellow leaf spot or nutritional disorders such as aluminium toxicity or zinc deficiency.

The only other disease that has black fruiting bodies within the blotches is *Septoria nodorum* blotch, but this disease is rare in Victoria. [62]

9.3.4 Conditions favouring development

Septoria tritici blotch survives from one season to the next on stubble. Following rain or heavy dew in late autumn and early winter, wind-borne spores (ascospores) are released from fruiting bodies (perithecia) embedded in the stubble of previously infected plants. These spores can be spread over large distances. Early ascospore infections cause blotches on the leaves. Within these blotches a second type of fruiting body, pycnidia, are produced. Asexual spores ooze from pycnidia when the leaf surface is wet and spores are dispersed by splash to other leaves where they cause new infections. This phase of disease development depends on the rain splash of spores; therefore STB will be most severe in seasons with above average spring rainfall. A combination of wind and rain provides the most favourable conditions for spread of this disease within crops. [63]

62 G Hollaway (2007) *Septoria tritici* blotch of wheat. Agriculture Victoria, December 2007, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/septoria-tritici-blotch-of-wheat

63 G Hollaway (2007) *Septoria tritici* blotch of wheat. Agriculture Victoria, December 2007, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/septoria-tritici-blotch-of-wheat

9.3.5 Management of disease

The best management strategy remains the avoidance of the most susceptible varieties, particularly with early sowing. [64] An integrated approach that incorporates crop rotation/stubble avoidance, variety selection and fungicides can provide effective suppression of STB. Identification of strains with partial resistance to common fungicides highlights the need to adopt an integrated control approach to slow the further development of resistance to fungicides. Since STB is primarily a stubble-borne disease, both crop rotation and stubble management contribute to disease control. In most instances, a one-year break from wheat is effective in reducing early disease occurrence, but during dry seasons a two-season break may be required. Any tillage that reduces stubble on the surface (such as burial, burning or grazing) can reduce inoculum levels, but these practices need to be balanced with the risk of soil erosion. Stubble management will not reduce disease caused by spores blown in from other paddocks. Avoiding susceptible and very susceptible varieties (ratings of S, SVS or VS) is an effective strategy to reduce in-crop disease severity and historically has provided long term disease control. Since STB is pathogenically diverse (that is, different strains can attack different varieties), and resistance breakdown is known to occur, it is important to consult a current disease guide each year. With support from GRDC and Agriculture Victoria, a new STB screening nursery was established at Hamilton to screen Australian National Variety Trials entries and pre-breeding lines. These results contribute to the ratings published in the cereal disease guide. [65]

MORE INFORMATION

Septoria tritici blotch fact sheet – Southern region

In-crop fungicides and timing

Fungicides can contribute to STB control, especially during wet seasons. In high risk areas the timing of fungicides is important to achieve adequate disease control. In early sown susceptible varieties, where infection is established during autumn, an early fungicide application at Z31–32 may be required to suppress the disease and protect emerging leaves. Another fungicide application may be required once the flag leaf has fully emerged at Z39 to protect the upper canopy.

Foliar fungicides registered to control this disease are available, but they are not entirely effective and there is a threat of fungicide resistance developing, especially with the strobilurins if they become used too frequently and when disease levels are high. Since STB is developing resistance to fungicides, it is critical that strategies are implemented that reduce the likelihood of further resistance developing. 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. [66]

MORE INFORMATION

APVMA website

Increasing resistance of *Zymoseptoria tritici* to some triazole (Group 3) fungicides was recently detected in Victoria by Dr Andrew Milgate, NSW Department of Primary Industries. Two mutations of STB giving resistance to triazole fungicides were identified. These mutations reduce the effectiveness of fungicides, rather than making them completely ineffective. However, continued use of triazole fungicides will put further selection pressure on the pathogen, and potentially new mutations will be selected. [67]

Fusarium head blight

Fusarium head blight (FHB) is a fungal disease that can occur on many grass species, including both crop and weeds. Where it occurs in crops it is most commonly in wheat, durum and barley. The crown rot fungus is a closely related species, Fusarium

64 M Evans, H Wallwork (2016) Cereal pathology watch list for 2016. GRDC update papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-pathology-watch-list-for-2016

65 G Hollaway, M McLean, J Fanning (2016) Cereal disease management in Victoria 2016. GRDC update papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Cereal-disease-management-in-Victoria-2016

66 GRDC (2014) *Septoria tritici* blotch fact sheet. Grains Research and Development Corporation, February 2014, http://www.grdc.com.au/GRDC-FS-Septoria-Tritici-Blotch-Wheat

67 G Hollaway (2007) *Septoria tritici* blotch of wheat. Agriculture Victoria, December 2007, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/septoria-tritici-blotch-of-wheat

pseudograminearum. Durum is more susceptible to the FHB than bread wheat and barley. Durum crops should be avoided in areas where there is a likelihood of the disease developing. While FHB can be caused by several species of Fusarium, the most common species causing the disease is Fusarium graminearum. Fungal infection can sometimes be associated with the production of a toxin (mycotoxins). If fungal toxins are produced in infected seed, the grain is often unacceptable for certain end uses and downgraded in the marketplace depending on the concentration of toxin present. Toxin levels and fungal infection cannot be accurately estimated from visual appearance. Crop rotation is effective in reducing levels of FHB.

9.3.6 Damage caused by disease

Fusarium head blight can cause significant yield losses and quality reductions. Major yield losses occur mainly from floret sterility. Additional yield and quality losses can occur when damaged and shrivelled lightweight grains are produced as a result of infection. Quality reductions may also occur from seed discoloration, varying from whitish-grey and pink to brown. [68]

9.3.7 Symptoms

In wheat and durum, any part or all of the head may appear bleached (Photo 7). Heads that are partly white and partly green are one of the diagnostic symptoms in wheat for the disease, but can easily be confused with white grain disorder.

Photo 7: *Fusarium head blight may cause bleaching of any part or all of the durum head.*

Source: Department of Agriculture and Fisheries Queensland

A brown/purple discolouration on the stem tissue or on the peduncle (immediately below the head) in infected heads is another distinguishing factor that can be seen in heavily FHB-infected crops. Discolouration on the stem tissue or peduncle without the bleaching may be due to other causes such as physiological melanism. Additional symptoms that occur during prolonged wet weather and heavy infection of FHB are pinhead-sized, pink to salmon-orange spore masses on infected spikelets and glumes (Photo 8).

68 DAFQ (2015) Fusarium head blight, or head scab. Queensland Department of Agriculture and Fisheries, April 2015, https://www.daf.qld.gov.au/plants/health-pests-diseases/a-z-significant/fusarium-head-blight

Photo 8: *Symptoms of Fusarium head blight may include pink to salmon-orange spore masses on infected spikelets and glumes.*

Source: Department of Agriculture and Fisheries Queensland

Depending on how soon after flowering bread and durum wheats are infected, grain can have different severities of aborted kernels, shrivelled seed, low test weight and grain discolouration. If disease infection occurs later in grain development, Fusarium-infected seed may be normal in size but it may have lost its amber translucence and will appear chalky or opaque or pink (Photo 9).

Photo 9: *Fusarium-infected seed may be normal in size but it may have lost its amber translucence and will appear chalky or opaque or pink.*

Source: Department of Agriculture and Fisheries Queensland

The best rotational crops for reducing the FHB inoculum level include any non-grass species (e.g. chickpeas, faba bean, canola, field peas). Currently, no seed dressings are registered for control of seedling blight caused by the FHB pathogens.

For more information see Section 9.2.5 Management of crown rot, or Section 1 Planning and paddock preparation.

Plant growth regulators and canopy management

Key messages

- Adopting canopy management principles and avoiding excessively vegetative crops may enable growers to better match canopy size with yield potential as defined by the water available.
- Other than sowing date, plant population is the first point at which the grower can influence the size and duration of the crop canopy.
- Upfront nitrogen increases tiller numbers and in many cases final ear number but may not necessarily increase yield.
- Crop responses to the use of plant growth regulators (PGRs) can be inconsistent.
- PGRs must be applied at the correct crop growth stage according to product directions, which can be well before any lodging issues are apparent.

10.1 What is canopy management?

Canopy management is managing 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 determines the crop's photosynthetic capacity and therefore its overall grain productivity. [1]

Growth in cereals can be thought of in two distinct parts: 1) pre-flowering (pre-anthesis) growth, which is the growth of leaves, roots and stems before a crop flowers and sets yield potential; and 2) post-flowering growth, the majority of which goes into grain. The aim of canopy management is to get the balance right between pre- and post-anthesis growth to maximise grain yield, quality and harvestability in any given season. In drier environments crop canopies that produce excessive growth (tillers) by virtue of paddock fertility (soil nitrogen or applied nitrogen) use more of the water available pre-flowering, leaving less for grainfill. This may result in lower yields and poor grain size. Conversely, overly thin crop canopies that have adequate water available, produce insufficient crop canopy pre-flowering to fully take advantage of the water available for grainfill post-flowering. [2]

For more information on growth stages see Section 4: Plant growth and physiology.

Where this management system has been developed (principally in Europe and New Zealand) it has shifted grower focus from lush, thick crop canopies to thinner, more open, canopies (Photo 1). At its simplest, the technique could be represented by a simple comparison of crop canopies.

Growers practicing canopy management have target canopy sizes for specific growth stages, and nitrogen (N) management is tailored to adjust the crop to these targets. If the canopy is too thin, the timing of N fertiliser application is brought forward; if it is too thick, N timing is delayed. Soil moisture and expected rainfall for the remainder of the season are key factors to consider when deciding how much nitrogen to apply and when to apply it. In some seasons, several applications of nitrogen are required. Plant populations influence canopy development and management of plant populations in relation to sowing date can have a significant impact on crop biomass.

1 GRDC (2005) Cereal growth stages. Grains Research and Development Corporation, September 2005, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

2 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

Photo 1: *Wheat grown in Victoria's high rainfall zone, near Geelong, treated with the same level of nitrogen. The crop on the left has a thinner crop canopy; it yielded 6.18 t/ha and 12.0% protein, compared to the thicker canopied crop on the right, which yielded 6.20 t/ha and 10.6% protein.*

Source: Grains Research and Development Corporation

In Photo 1, above, is an example of a thinner crop canopy (left) which yielded 6.18t/ha and 12% protein, and thicker crop canopy (right) which yielded 6.20 t/ha and 10.6% protein. The crop was Kellalac wheat, sown 11 June in Gnarwarre, Victoria (in the high rainfall zone); both paddocks were treated with same level of N.

Adopting canopy management principles and avoiding excessively vegetative crops may enable growers to ensure a better match of canopy size with yield potential as defined by the water available.

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. Other than sowing date, plant population is the first point at which the grower can influence the size and duration of the crop canopy [3] and one of the main tools for growers to manage the crop canopy is the rate and timing of applied fertiliser 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 grainfilling period.

10.2 Canopy management in a nutshell

1. Select a target head density for your environment (350 to 400 heads/m^2 should be sufficient to achieve optimum yield even for yield potential of 7 tonnes per hectare).
2. Adjust canopy management based on paddock nutrition, history and seeding time to achieve target head density.
3. Established plant populations for wheat of between 80 and 200 plants/m^2 would cover most scenarios but durum crops should target the high end of sowing rates.
4. Lower end of range (80–100 plants/m^2): are appropriate for earlier sowings/high fertility and or low yield potential low rainfall environments.
5. Higher end of the range (150–200 plants/m^2): later sowings, lower fertility situations and or higher rainfall regions and durum for weed competitiveness.

3 GRDC (2005) Cereal growth stages. Grains Research and Development Corporation, September 2005, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

VIDEOS

WATCH: On-farm storage in the SA Mallee with Corey Blacksell.

WATCH: On-farm storage in SA—Linden Price

WATCH: Over the Fence: On-farm storage delivers harvest flexibility and profit

WATCH: Stay safe around grain storage

6. During stem elongation (GS30–39), provide the crop with necessary nutrition (particularly N at GS30–33 pseudo stem erect—third node), matched to water supply and fungicides, to:
7. maximise potential grain size and grain number per head;
8. maximise transpiration efficiency;
9. ensure complete radiation interception from when the flag leaf has emerged (GS39); and
10. keep the canopy green for as long as possible following anthesis.

Keeping tiller number just high enough to achieve potential yield will help preserve water for filling grain and increase the proportion of water soluble carbohydrates. The timing of the applied N during GS30–33 window can be adjusted to take account of target head number. Earlier applications in the window (around GS30) can be employed where tiller numbers and soil N seems deficient for 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 less tillers surviving to produce a head. Further applications of nitrogen can be made as the crop progresses into booting (GS 45). Much of the research on topdressing N has focused on the role of in-crop N to respond to seasons in which yield potentials have increased significantly due to above-average rainfall conditions. In these situations, research has shown that positive responses can be achieved, especially when good rainfall is received after N application. [4]

10.2.1 Limitations of tactical nitrogen application

The main limitation to tactical N application is the ability to reliably apply N before a rain event, to enable roots to access soluble N in the root-zone. Predicted rain fronts may pass without yielding anything; therefore, dependably applying N throughout the season has some risk. However, urea losses are extremely low during cold winter months and application of urea onto well -developed canopies assist in minimizing losses. Paddock trafficability is important, with an application of urea during or after a rainfall event onto wet soils being more beneficial to the crop than waiting for the next significant rainfall to occur and effectively applying the nitrogen at a later than optimum timing. Presswheel furrows can also aid nitrogen uptake as much of the fertiliser falls into the furrow where surface moisture levels are higher.

Foliar N application is gaining popularity; however, this is only suitable for relatively low rates of N addition and are generally more expensive. Foliar N applications are generally no more efficient than solid forms of nitrogen fertiliser. [5]

> *You can apply high rates in a liquid N form (i.e. UAN), with streaming nozzles, but there is a limit to how much N is actually taken in via the foliage. The remainder relies on root uptake. The advantage is that loss rates of a liquid N form are significantly lower than urea if you don't get sufficient rainfall to wash it in compared to urea. The downside is that UAN is generally a more expensive product per kg of N supplied.*

Agronomist's view

As technologies such as normalised difference vegetation index imaging and paddock management in zones become prevalent, the addition of N later in the crop cycle will become more relevant and will force the development of equipment to make such a system work.

Based on sound trials and paddock experience, the aim of improving the economic outcome at the end of the season through manipulation of the most costly input is

4 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

5 Bill Long (2016). Personal communication.

taking shape. Adoption of these techniques in regions where winter rainfall is less frequent would be further aided by development of efficient, in-soil N application equipment. [6]

10.3 Row spacing, seed rate and nitrogen fertiliser manipulation

The traditional row spacing in much of southern Australia has been 15 to 20 cm (Figure 1). Greater adoption of no-till farming systems has increased interest in wider row spacing such as 30 to 50 cm, depending on the crop type and region. However, increasing row spacing is not always beneficial to yield. [7]

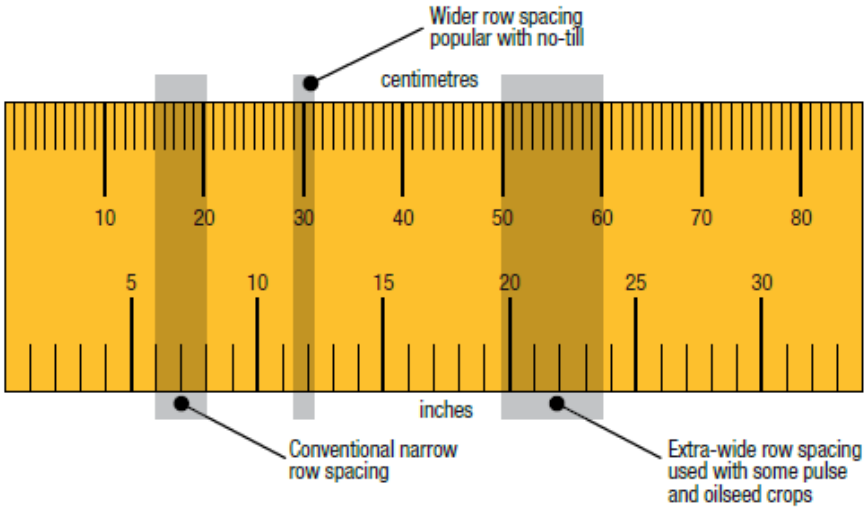


Figure 1: *Common row spacings in metric and imperial measurements.*

Source: Grains Research and Development Corporation

Yield:

- There are a number of reasons why growers might wish to pursue wider row spacing in cereals, for example, residue flow, inter-row weed and disease control. However, in a series of canopy management trials (2007–10) on wheat covering a wide range of rainfall environments in Victoria, South Australia and New South Wales, increasing row width reduced yield.
- The yield reduction in wheat was particularly significant when row width exceeded 30 cm.
- At row widths of 30 cm the reduction in wheat yield compared to narrower 20–22.5 cm row spacing was dependent on overall yield potential:
- At yields of 2–3 t/ha the yield reduction was negligible.
- At yields of 5 t/ha the yield reduction was between 5–7%, averaging about 6% (Photo 2).
- Data from a single site suggests that rotation position may influence the yield response in wider row spacing in wheat. Wheat after wheat suffered less yield reduction with wider rows than an equivalent trial at the same site which was in wheat after canola. [8]

6 Bill Long (2016). Personal communication.

7 GRDC (2011) Crop placement and row spacing fact sheet. Grains Research and Development Corporation, January 2011, https://grdc.com.au/Resources/Factsheets/2011/02/Crop-Placement-and-Row-Spacing-Southern-Fact-Sheet

8 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

Photo 2: *Narrow row spacing (left) and wide row spacing (right). The higher the yield potential, the greater the negative impact of wider rows on wheat yields.*

Source: Weedsmart

Plant spacing:

- Increasing row width decreases the plant-to-plant spacing within the row, leading to more competition within the row and reduced seedling establishment (for reasons that are not clearly understood) but most likely plant competition for resources such as light and water.
- Limited data indicates that increasing seeding rates, such that the average plant-to-plant spacing in the row drops below 2.5 cm, is either negative or neutral in terms of grain yield.
- Planting seed in a band (as opposed to a row) will increase plant-to-plant spacing but may increase weed germination and moisture loss through greater soil disturbance. [9]

Dry matter:

- Wider row spacing (30 cm and over) reduced harvest dry matter relative to narrower rows (22.5 cm and under). From crop emergence to harvest, differences were in the order of 1–3 t/ha depending on row width and growing season rainfall.
- The reduction in dry matter in wide rows was also significant at flowering (GS60–69). Frequently a 1 t/ha reduction resulted when row spacing increased 10 cm or more over a 20 cm row spacing base. This could be important when considering harvesting for hay rather than grain. [10]

Grain quality:

- The most noticeable effect of row width on grain quality was on protein: wider rows increased yield and diluted grain protein.
- Differences in grain quality were typically small in terms of test weights and screenings, with very small benefits to wider rows over narrow rows on some occasions. [11]

Nitrogen management

Nitrogen management did not interact with row spacing; optimum N regimes for narrow row spacing (22.5 cm or less) were the same as for wider row spacing (30 cm or more). The greater N efficiency observed with stem elongation applied N was more important with narrow row spacing since higher yields lead to a tendency for lower protein. [12]

9 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

10 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

11 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

12 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

10.3.1 Water and canopy management

Plants grow by intercepting solar radiation and must use water to do this. When plants are actively growing, they open the small holes (called stomata) on their leaf surfaces to let in carbon dioxide from the atmosphere, and this carbon dioxide is captured by the leaf's mesophyll cells and converted to dry matter through the process of photosynthesis. While the stomata are open, water evaporates from the mesophyll cell surfaces and escapes as vapour into the atmosphere. This process is called transpiration.

The amount of water a crop transpires per day is determined by the amount of leaf area a crop has per unit area of ground, water supply and the evaporative demand of the atmosphere (determined by the ambient temperature, solar radiation and wind). The amount of leaf area a crop has is measured as leaf area index (LAI) and is expressed in square metres of leaf area per unit of ground (m^2/m^2). For example, a crop with a LAI of 5.0 has 5 m^2 of leaf area per 1 m^2 of ground.

However, as the green area of the crop canopy is also composed of stems, leaf sheaths and the heads, the overall green area of canopy is described as the green area index (GAI). Cereal crops also have stomata on their stems, heads and leaf sheaths, and these areas contribute significantly to plant growth, particularly after anthesis. The rate at which plants are able to grow per unit of water transpired is called transpiration efficiency (TE), and is expressed as kilograms per hectare of dry matter per millimetre of transpiration (kg/ha/mm). Across a growing season, wheat plants generally have a TE for above-ground dry matter of between 50 and 60 kg/ha/mm. Factors that affect TE include nutrition (for example N stressed crops do not transpire as efficiently as crops with adequate N), the temperature and humidity of the atmosphere (the drier and warmer the atmosphere, the less efficient the plants) and the genetic make-up of the crop variety. [13]

10.4 New tools to lift canopy management potential

New tools to fight leaf diseases and respond to crop N needs have been developed for cereal growers in the high rainfall zone, following a three-year project by the Foundation for Arable Research.

Thirty-nine trials across the southern grains region showed that the use of crop sensors to assess the need for topdressed N at stem elongation have the potential to save up to $60/ha in fertiliser costs.

The trials showed a strong relationship between N uptake and sensor readings from late tillering to the third node, if appropriate test strips are used to calibrate the figures. This relationship is particularly useful to assess the degree of N available to the crop in spring. Linked with crop models in the future, it is envisaged that crop sensors could enable growers to better visualise the growth of their crops. The use of crop sensors may have a greater role where N applications are split. The sensor can be used after the first topdressing to determine whether a second application of N is warranted on parts of the paddock.

Trials in Tasmania found that for early sown (March or April), long season wheat, grazing before stem elongation prevented lodging and is more effective than other methods. However, in a wet spring, this was also associated with yield loss. The other factors found to reduce lodging were, in order of importance, variety choice, cutting sowing rates, applying plant growth regulators or delaying N. [14]

Key findings of the trials were:

- An average 6% yield penalty, but higher protein content, from wheat sown on 30 cm row spacing, compared with 20 or 22.5 cm, in crops yielding above 5 t/ha.

13 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

14 F Pritchard (2013) New tool lifts canopy management potential. Ground Cover Issue 105. Grains Research and Development Corporation, July 2013, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-105-July-August-2013/New-tool-lifts-canopy-management-potential

MORE INFORMATION

GRDC Canopy management guide

- Row spacing had little effect on yields for crops yielding 2 to 3 t/ha.
- Nitrogen requirements and optimal timing were the same, regardless of the row spacing.
- Ideally, growers should avoid planting seeds less than 2 cm apart within a row when sowing with wide rows, due to competition between plants.

10.5 Plant growth regulators

A plant growth regulator (PGR) is an organic compound, either natural or synthetic, that modifies or controls one or more specific physiological processes within a plant. PGRs are any substance or mixture of substances intended, through physiological action, to accelerate or retard the rate of growth or maturation, or otherwise alter the behavior of plants or their produce. [15]

PGRs are used to minimise crop lodging, shorten plant height and maximise yield, particularly in high N situations that promote heavy canopies. Attempting to grow high yielding irrigated crops requires high levels of inputs, including water and fertiliser, which can promote large vegetative crops that are prone to lodging. Lodging can result in reduced yields and difficulties in harvesting. PGRs have been around for many years but results can be variable and can have negative effects on yield in some circumstances.

Key points:

- Crop responses to the use of PGRs can be inconsistent.
- In Irrigated Cropping Council trials yield increases directly attributable to the use of PGRs have been measured in barley but not wheat. Other trials have demonstrated significant increases in wheat and barley yields in the absence of lodging.
- PGRs must be applied at the correct crop growth stage, which can be well before any lodging issues are apparent.

PGRs are chemicals which are used in various crops to manipulate the production of certain hormones, in particular gibberellic acid (GA) and ethylene (Ethephon). These hormones are produced by the plant at particular growth stages. By manipulating the amount of hormone produced by the crop, the plant height and stem strength can be influenced. Decreasing plant height and improving stem strength, reduces the amount of lodging and in some cases, increases Water Use Efficiency (WUE). [16] More recently, trinexipac ethyl has been registered for use in wheat and barley. Trials with this product demonstrate more consistent yield gains and reduced crop lodging as well as reduced head loss in barley. [17]

Inconsistent results from PRG applications

In a trial conducted in Narrabri, New South Wales, a combination of two PGRs increased yield by 16% when applied at GS31. Wheat was sown on 30 cm row spacings into a 2 m flat bed. Approximately 150 seedlings emerged and the site was irrigated via flood furrow. Nitrogen was applied at sowing (180 kg/ha) and the site had less than 30 kg/ha residual soil nitrate/90 cm soil. Despite no lodging being observed, a significant positive effect on yield was achieved using the products in this experiment when applied at the booting stage. This trend has been consistent through several experiments conducted using these products and mixtures. [18]

Another trial was conducted in 2006 at Benerembah, west of Griffith, to measure the influence of PGRs, varying N rates and application times on grain yield and quality

15 P Lemaux (1999) Plant growth regulators and biotechnology, http://ucbiotech.org/resources/biotech/talks/misc/regulat.html

16 B Haskins (2008) Durum wheat and barley canopy management, Hillston. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/Durum-wheat-and-barley-canopy-management-Hillston.pdf

17 Bill Long (2016). Personal communication.

18 B Griffiths, L Bailey, C Guppy, N Hulugalle, C Birchall (2013) Managing resources and risk for 8 tonne cereal crops. GRDC Update Papers. Grains Research and Development Corporation, March 2013, https://grdc.com.au/Research-and-Development/%20GRDC-Update-Papers/2013/03/Managing-resources-and-risk-for-8-tonne-cereal-crops

MORE INFORMATION

Durm wheat and barley canopy management, Hillston.

Plant growth regulators

Plant growth regulators in broad acre crops

PGRs and their agronomic and economic benefits to high yield potential cereal, pulse and oilseed crops

Good things come in small packages: plant growth regulators in barley

Mixed bag—dual purpose crops, PGRs and other local research—Tasmania.

of durum wheat on flood irrigation. Two durum wheat varieties (EGA Bellaroi(D) and Jandaroi(D)) were planted using a small plot cone seeder at a sowing rate of 220 plants/m^2 (roughly 110 kg/ha). In the absence of lodging as with Bellaroi(D), PGRs at DC31 actually reduced yield. When the crop lodged as it did in Jandaroi(D), yield was maintained by using PGRs. In this trial PGRs were not economically viable, as they reduced or only maintained yield potential The researchers put these inconsistencies in yield and poor yield result down to poor seasonal conditions and suggest that PGRs may have a role in some season but not others. [19]

PGRs may have a place in the management of high yielding crops. Unfortunately, their effects are not consistent and the decision on whether to apply the PGR has to be made at approximately three months before the lodging would be expected.

Alternative PGRs are available but are not yet registered for use on all crops or at rates and timings that would have a growth regulatory effect. [20]

Until recently in Australia, the range of PGR's available to growers was limited to chlormequat chloride (wheat only) and ethephon (barley only) and the use of these products has generally been relatively low. The principle reason for this is simply that responses are viewed as variable and growers have not regularly seen the benefit of incorporating them into their management programs.

More recently a new PGR combination of trinexapac-ethyl and chlormequat applied at GS31 has been found to provide significant and consistent yield gains in wheat (11%) and barley (9%) under dry spring conditions. They also significantly reduced plant height, lessening the possibility of lodging in wetter seasons. [21] Overseas, chlormequat chloride has been found to inhibit gibberellin production and has been recommended in winter and spring rye, wheat, oats, triticale and winter barley. [22]

Moddus® Evo

Key points

- Moddus® Evo reduces lodging and can increase yields.
- Application timing and concentration of Moddus® Evo is critical.
- Moddus® Evo should not be applied to plants under stress.
- Moddus® Evo has improved formulation stability and plant uptake.

Lodging is considered one of the biggest barriers to reliably achieving high yields in intensive cereal production in Australia. When favourable season conditions combine with traditional management practices in high input cereal production systems, lodging can result in significant reductions in yield and grain quality.

Moddus® (250 g/L trinexapac-ethyl) is used by cereal growers in a range of overseas countries including New Zealand, UK and Germany to reduce the incidence and severity of lodging and optimise the yield and quality of high yielding wheat, barley and oat crops. Moddus® Evo is an enhanced dispersion concentrate (DC) formulation which has been developed to provide greater formulation stability and more effective uptake in the plant. With improved mixing characteristics and the potential to provide better consistency of performance Moddus® Evo is currently submitted to the APVMA for registration in Australian cereals.

The purpose of this research was to investigate the value of Moddus® applications to Australian cereals to reduce lodging and improve yields.

19 IREC. Crop canopy management through nitrogen plant growth regulators. Farmer newsletter no. 175. Irrigation Research and Extension Committee,

20 D Jones (2014) GRDC Update Papers: Plant Growth Regulators, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators

21 W Long (2005) GRDC Final reports: AC0003—Plant growth regulators and their agronomic and economic benefits to high yield potential cereal, pulse and oilseed crops, http://finalreports.grdc.com.au/ACC00003

22 BASF. How do PGR's work? http://www.agricentre.basf.co.uk/agroportal/uk/en/crop_solutions/cereals_5/lodging___canopy_managememt/canopy_management_in_cereals.html

Methods

Field trials were run across Australia from 2004 to 2011. A range of varieties, climatic conditions and geographical locations were used. Trials were established as small plots, typically 20–120m^2 using a randomised complete block design, incorporating 3–6 replicates.

Measurements were taken of the effect of Moddus® application on plant growth, stem strength, stem wall thickness, lodging, lodging score, yield, as well as grain quality measurements.

Results

Overall improvements in yield were often correlated with a reduction in stem height irrespective of whether lodging occurred or not. Yield improvements through the reduction of lodging are well documented. What is less understood is the often positive impact on yields with the use of Moddus® Evo in the absence of lodging.

Conversely during the course of the evaluation of Moddus® Evo on the yield enhancement and reduction in lodging there were a few trials with anomalous results, where Moddus® Evo application did not improve yield. When these trials were examined it was found that either environmental conditions during the lead up to the Moddus® Evo application were poor, with extensive frosting, drought, poor subsoil moisture profile or nutrient deficiencies within the crop. As a result Moddus® Evo should only be applied to healthy growing crops with optimum yield potential.

Moddus® Evo offers growers in environments conducive to lodging an in-season option to reduce the impact of lodging while allowing them to manage crops for maximal yields. The timing and concentration of Moddus® Evo applications is critical to produce the optimal yield improvements. Moddus® should only be applied to healthy growing crops. Moddus® Evo is a new generation plant growth regulator offering improved yield potential to Australian cereals.

MORE INFORMATION

Moddus® Evo: Controlling plant growth for reduced lodging and improved cereal yields.

Crop desiccation/spray out

Not applicable for this crop

Harvest

Key messages:

- Durum is ideally harvested when it reaches a moisture limit of 12.5% but growers with high moisture management facilities can harvest earlier, reducing the risk of weather damage.
- To reduce chaff and whiteheads make sure harvester settings are correct.
- Ensure that harvesting equipment is clean to avoid contamination, and ensure headers are clear to lower the risk of fire.
- Headers need to be blown down with compressed air regularly during harvest to prevent dust buildup around exhaust manifolds and other hot components
- Premiums are paid for high-protein durum grain that is large and undamaged, without mottling, bleaching or contamination.
- Black point-affected durum grain can receive a price reduction
- Concave adjustments might be necessary as durum can be slightly more difficult to thresh than most bread wheats.

Growers should monitor market receival standards and any changes made each year. Harvesting can commence whenever the header is capable of giving a clean grain sample. This is usually when grain moisture is <20% and ideally 12.5% . 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 76 kg/hectolitre (HL), although durum wheat often achieves 80 kg/hL. [1]

Photo 1: *Dryland durum wheat being harvested on 'Keytah' in 2009 using controlled traffic set up harvesters and chaser bins, owned by contractors, on three metre wheel spacings.*

Photo: Kellie Penfold, Source: GRDC

1 DAFQ (2012) Harvesting and yield. Department of Agriculture, Fisheries and Forestry Queensland, September 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/harvesting-information

12.1 Wet harvest issues and management

Ideally, harvest begins as soon as the crop is mature or ripe (Photo 1). 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, a grower with aerated storage could harvest at around 15% MC, while a grower without high moisture management techniques would have to wait until the moisture was <12.5%.

Figure 1 below highlights how harvesting at higher moisture levels can allow an earlier start to harvest, reduce exposure to weather events and result in a shorter total harvest period. The potential harvest period at higher moisture levels spans three weeks (week two to week five) but traditional harvesting, at 12.5% MC, spans four weeks (week three to week seven). The delayed start and longer overall duration when harvesting at traditional moisture levels results in the crop being at risk of potential loss of quality for two extra weeks. For example, significant rainfall event in week five might cause substantial quality loss and hence a significant reduction in the crop's value. [2]

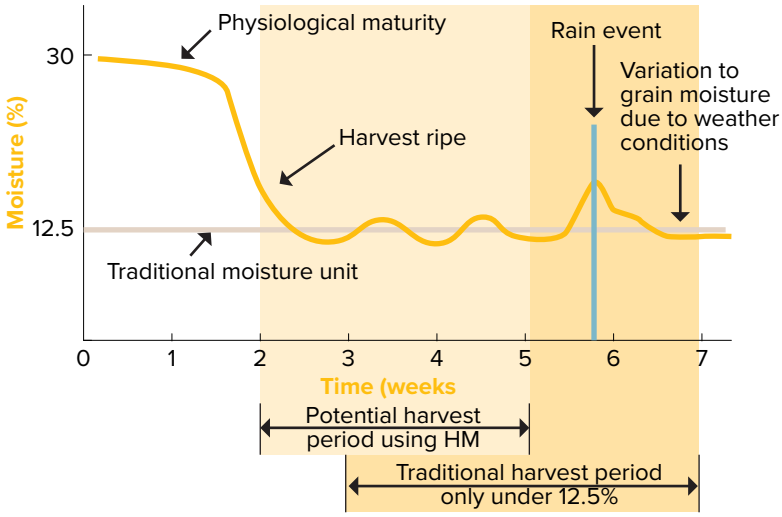


Figure 1: *Grain moisture and harvest period.*

Source: South East Premium Wheatgrowers Association

12.1.1 Delaying harvest

Every day a crop stands in the paddock it is exposed to ongoing yield loss and quality degradation. 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, Western Australia, revealed daily DM losses of 0.18–0.53% DM for wheat and 0.25–0.75% DM for barley (depending on the season and distance from the ocean). [3] Most growers have also experienced some form of grain quality loss due to delayed harvest. For example, if there is

2 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, Western Australia, http://www.giwa.org.au/_literature_133719/SEPWA_and_CBH_Group_-_the_WA_Guide_to_high_moisture_harvest_management_grain_storage_and_handling

3 MD Bolland, JD Richardson (1984) Time of harvesting barley and wheat near Esperance, Western Australia. Department of Agriculture and Food, Western Australia. Technical Bulletin 66, http://researchlibrary.agric.wa.gov.au/tech_bull/79/

substantial rain, wheat begins to sprout, reducing its flour quality characteristics; and fungal growth reduces the end use possibilities.

These factors can combine to result in heavy discounts, reducing the 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).

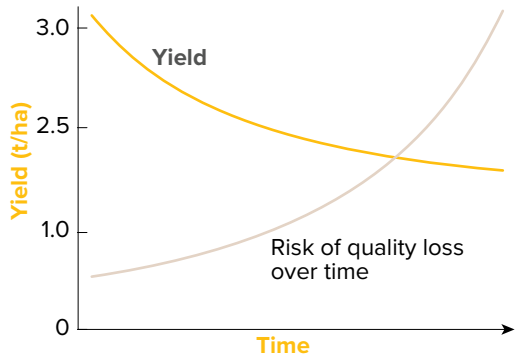


Figure 2: *Crop yield and risk of quality loss over time.*

Source: South East Premium Wheatgrowers Association

12.2 Dry harvest issues and management

The crop should be harvested as soon as the grain reaches maturity to avoid weather damage. Buyers consider grain appearance important and seek large, well-filled vitreous grain with a low percentage of mottled or bleached grains. Header cleaning is also critical to prevent contamination with barley or other cereals. [4]

Premiums are only paid when grain is large and undamaged; not mottled, bleached or—most importantly—contaminated by other grains; and meets all other delivery specifications. Grain harvester machine settings, careful segregation, and clean, insect-free grain storage must receive attention. Damaged, contaminated or insect-infested grain will be downgraded. Durum wheat is a high quality product trading into a high quality food market and attention to detail at harvest is critical. [5]

Concave adjustments might be necessary as durum can be slightly more difficult to thresh than most bread wheats. Take care when adjusting headers, as durum grain has a greater tendency to fracture than bread wheat grain. Some varieties can be prone to shelling, a factor of significance when wind and rain prevail at harvest. All grain should be retained in the head despite these weather conditions. Care needs to be exercised when threshing the crop, due to the grain's tendency to fracture. Buyers of durum grain consider grain appearance important and pay premiums for large, well-filled, hard, vitreous grain with a low percentage of mottled and bleached seeds. [6]

Although durum wheats have slightly better resistance to pre-harvest sprouting than current bread wheats, they may be downgraded to feed due to bleaching and softening of the grain in prolonged wet harvest seasons. [7]

4 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries Management Guide, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

5 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

6 R Hare (2006) Agronomy of the durum wheats Kamilaroi(), Yallaroi(), Wollaroi() and EGA Bellaroi(). Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

7 DAFQ (2012) Durum wheat in Queensland. Department of Agriculture and Fisheries Queensland, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

When harvesting severely lodged wheat:

- Try harvesting in different directions to find the angle at which the header best picks up the wheat.
- Adjust the reel slightly ahead of the cutter bar and far enough down to lay the head on the platform.
- The reel should turn slightly faster than ground speed. [8]

Managing wheat residue:

- Wheat straw should be baled or spread uniformly with the combine.
- Leaving heavy amounts of residue on the ground may result in poor seed/soil contact during planting. [9]

12.3 Fire prevention

Grain growers must take precautions during the harvest season, as operating machinery in extreme fire conditions is dangerous. They should take all possible measures to minimise the risk of fire. Fires are regularly experienced during harvest in stubble as well as standing crops. The main cause is hot machinery combining with combustible material. This is exacerbated on hot, dry, windy days. Seasonal conditions can also contribute to lower moisture content in grain and therefore a greater risk of fires.

Harvester fire reduction checklist

1. Recognise the big four factors that contribute to fires: relative humidity, ambient temperature, wind and crop type and conditions. Stop harvest when the danger is extreme.
2. Focus on service, maintenance and machine hygiene at harvest on the days more hazardous for fire. Follow systematic preparation and prevention procedures.
3. Use every means possible to avoid the accumulation of flammable material on the manifold, turbocharger or the exhaust system. Be aware of side and tailwinds that can disrupt the radiator fan airblast that normally keeps the exhaust area clean.
4. Be on the lookout for places where chaffing can occur, such as fuel lines, battery cables, wiring looms, tyres and drive belts.
5. Avoid overloading electrical circuits. Do not replace a blown fuse with a higher amperage fuse. It is your only protection against wiring damage from shorts and overloading.
6. Periodically check bearings around the harvester front and the machine. Use a hand-held digital heat-measuring gun for temperature diagnostics on bearings and brakes.
7. Maintain fire extinguishers on the harvester and consider adding a water-type extinguisher for residue fires. Keep a well maintained fire fighting unit close-by to the harvesting operation ready to respond.
8. Static will not start a fire but may contribute to dust accumulation. Drag chains or cables may help dissipate electrical charge but are not universally successful in all conditions. There are some machine mounted fire-suppression options on the market.
9. If fitted, use the battery isolation switch when the harvester is parked. Use vermin deterrents in the cab and elsewhere, as vermin chew some types of electrical insulation.
10. Observe the Grassland Fire Danger Index (GFDI) protocol on high fire risk days.

8 DuPont Pioneer (2013) Crop focus: wheat harvest tips. DuPont Pioneer Agronomy Sciences, https://www.pioneer.com/CMRoot/Pioneer/US/Non_Searchable/agronomy/cropfocus_pdf/wheat_harvest_tips.pdf

9 DuPont Pioneer (2013) Crop focus: wheat harvest tips. DuPont Pioneer Agronomy Sciences, https://www.pioneer.com/CMRoot/Pioneer/US/Non_Searchable/agronomy/cropfocus_pdf/wheat_harvest_tips.pdf

11. Maintain two-way or mobile phone contact with base and others and establish a plan with the harvest team to respond to fires if one occurs. [10]

Using machinery

To preventing 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 outdoors:

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, as these components can drop hot metal onto the ground, starting a fire.

Use machinery correctly, as 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.

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, as this can reduce onboard ignitions. [11]

With research showing an average of 12 harvesters burnt to the ground every year in Australia (Photo 2), agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses.

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. [12]

Photo 2: *GRDC figures show that there are 1000 combine harvester fires in Australia each year.*

Source: Weekly Times

10 Barr R. (2015). Plant of attack needed for harvester fires. https://grdc.com.au/Media-Centre/Media-News/South/2015/10/Plan-of-attack-needed-for-harvester-fires

11 NSW Rural fire Service. Farm firewise. NSW Government, http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161

12 GRDC (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

12.3.1 Harvesting in low-risk conditions

Growers can use the Grassland Fire Danger Index guide to assess the wind speed at which harvest must cease (a GFDI of 35), depending on the temperature and relative humidity (Figure 3).

Step 1: Read the temperature on the left hand side.

Step 2: Move across to the relative humidity.

Step 3: Read the wind speed at the intersection. In the worked example, the temperature is 35oC and the relative humidity is 10 per cent so the wind speed limit is 26kph.

TEMP °C	5	10	15	20	25	30	40	50	60	65	RH%*
15	31	35	38	40	43	45	49	53	56	58	AVERAGE WIND SPEED (KPH)
20	29	33	36	38	40	43	46	50	53	55	
25	27	30	33	36	38	40	44	47	50	52	
30	25	28	31	33	35	37	41	44	47	49	
35	23	26	28	31	33	35	38	41	44	46	
40	21	24	26	28	30	32	35	39	41	43	
45	19	22	24	26	28	30	33	36	39	40	
TEMP °C	5	10	15	20	25	30	40	50	60	65	RH%*

*RH% *(Relative Humidity rounded down)*
†Wind speed averaged over 10 minutes

Figure 3: *Grassland fire danger index guide.*

Source: CFS South Australia

12.4 Receival standards

Some of the main aspects of grain quality are considered at receival:

1. Protein
2. Test weight
3. Screenings
4. Falling number
5. Black point
6. Weed seed contamination

The hard vitreous kernel (HVK) endosperm section of the grain is the important part, as it is this fraction that is processed into semolina (a coarse flour) and, in turn, mixed with a little water to form a stiff dough under vacuum and extruded under pressure into pasta, forming various shapes—both long and short goods. The endosperm is the food supply or life support system for the developing embryo. The endosperm and embryo are 'wrapped up' in several layers of tissue called the aleurone, pericarp and testa. The embryo and outer grain layers are removed during milling, into the bran and pollard fractions, while the endosperm is reduced to semolina. The endosperm is composed of numerous constituents including starch, sugars, proteins, amino acids, minerals, fats, vitamins, enzymes, pigments and fibre. A large, well-filled grain with bright amber colour and oval shape with minimal crease length is required at receival.

Durum wheat varieties express a satisfactory level of resistance to pre-harvest sprouting compared with current bread wheat varieties. Weather-affected grain is soft, which reduces the semolina extraction in the mill. Weathered semolina gives low pasta-dough strength due to the partial enzymatic breakdown of starches

PODCAST

GRDC Podcasts: Harvester Fires.

MORE INFORMATION

GRDC Reducing Harvester Fire Risk: The Back Pocket Guide

An investigation into harvester fires

Plan of attack needed for harvester fires

and proteins. These small protein and starch molecules have reduced cohesive properties. Weak doughs make inferior pasta. High-protein durum grain with a bright amber bloom is certain to attract the best available premium price. It is not advisable to leave your durum harvest until last, relying on its weathering resistance. Its resistance is only relative to other varieties and will eventually fail. Weathered durum is not valuable and may be received as feed grain.

Grain with adequate protein is very hard, vitreous and free from mottling. For milling, a small percentage of mottled grains can be tolerated in top grades, but a greater proportion will result in downgrading and a reduced premium. Vitreous grain contains sufficient protein to combine all the starch granules; however, a shortage of protein will give a mottled, softer grain. Protein can be envisaged as the equivalent of cement, which binds the starch granules or the aggregate together. With insufficient cement, the aggregate will not all bind and thus the concrete will be weak and break down readily. The same is the case with mottled sectors in grain. The degree of mottling in individual grains, together with the percentage of mottled grains in the seed lot, both contribute to the 'flour' formation and consequent milling losses. 'Flour' or 'fines' has a lower economic value than that of semolina. Hard, vitreous grains shatter into rough aggregates and produce a high semolina yield.

The canning industry specifies high protein semolina for canned pasta. High protein pasta withstands the high pressure/temperature cooking and retorting processes in acidic tomato pasta. Further, this pasta retains its consistency on warming and serving by the consumer. Dry pasta manufacturers require acceptable levels of protein but not as high as those required by the canning industry. Low protein semolina is unsuitable for pasta making as it has insufficient protein to give the product acceptable keeping, cooking and eating consistency. EGA Bellaroi(Ɒ and the varieties Jandaroi(Ɒ and Caparoi(Ɒ, are highly suitable for pasta and couscous production which are regarded by many Italian manufacturers as being equivalent to the best in the world.

The protein content of grain is largely under environmental control. Plants growing in soils with adequate nitrogenous fertility will lay down acceptable protein levels in the grain. The grain protein comprises a large number and complex range of protein types. The proteins range from short molecules to long, folding molecules. The long molecules adhere to each other and form an interlocking network, which prevents the starch and other components from moving freely. The degree of interlocking (chemical bonds) between these long-chained proteins determines the mobility of the pasta dough, which is called the 'dough strength'. Pasta dough strength, or the resistance of the dough to move under work (force), is mainly under genetic control. Cultivars that offer strong to very strong pasta doughs have been released. The dough strength, which is equivalent to protein strength, is a key determinant of pasta quality through its effect on the internal consistency of extruded products. Pastas made from strong protein doughs retain their shape and consistency on cooking and eating. Weaker pastas tend to break down during cooking. Bread wheat pastas are of this undesirable type.

The colour of pasta is a factor in consumer acceptance. Pale to white or brown pastas do not have a pleasing appearance and they are passed over for the bright, clear yellow pasta by the consumer. Only durum wheat can provide this colour without the addition of expensive synthetic pigments or egg products. The addition of artificial colours is banned in Italy and France. Law dictates that durum wheat must be used for dry pasta in these countries. Pasta colour is principally under genetic control; therefore, only highly coloured varieties are released. [13]

12.4.1 Hard vitreous kernel testing

The lack of an objective method for receival testing and binning of durum according to its hard vitreous kernel (HVK) percentage is costing the industry $20 to $40/t in quality claims. Through GRDC support, the Australian Durum Industry Association

13 R Hare (2006) Agronomy of the durum wheats Kamilaroi(Ɒ, Yallaroi(Ɒ, Wollaroi(Ɒ and EGA Bellaroi(Ɒ. Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

(ADIA) led the push for the development of a new objective HVK measurement based on existing near-infrared technology at the sample stand. A method with acceptable accuracy (plus or minus 4%) has been achieved as a result of collaboration between ADIA, BRI Australia, CSIRO, GrainCorp, ABB Grain, AWB and instrument manufacturer FOSS. The method is now being used to provide HVK testing on durum at delivery points across New South Wales and South Australia. Results are being recorded on weighbridge tickets. [14]

12.5 Harvest weed seed management

An important question needs to be answered: how can harvest weed seed practices be adopted to reduce soil weed seed banks to address herbicide resistance? And more specifically, how can growers get weed seeds into the header? [15]

Trials in both south-eastern and western Australian grain-growing regions have found a 55 to 58 per cent reduction, overall, in the emergence of annual ryegrass across the three main harvest weed-seed control (HWSC) systems being practised by growers. [16]

MORE INFORMATION

IWM manual section on harvest weed management.

IWM manual section on narrow windrow burning.

12.5.1 HWSC Strategies

Weed seed capture and control at harvest can assist other tactics to put the weed seed bank into decline. Up to 95% of annual ryegrass seeds that enter the harvester exit in the chaff fraction. If it can be captured, it can be destroyed or removed.

Western Australian farmers and researchers have developed several systems to effectively reduce the return of annual ryegrass and wild radish seed into the seed-bank, and help put weed populations into decline.

A key strategy for all harvest weed seed control operations is to maximise the percent of weed seeds that enter 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.'

Narrow windrow burning

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.

Windrow burning for weed control

- Continued reliance on herbicides alone is not sustainable in our continuous cropping systems. Rotating herbicides alone will not prevent the development of resistance
- Early implementation of windrow burning will prolong the usefulness of herbicides, not replace them
- Windrow burning is the cheapest non-chemical technique for managing weed seeds present at harvest
- Even with higher summer rainfall, windrow burning is a viable option for NSW cropping systems
- Windrow burning is an effective weed management strategy, even in the absence of resistance

14 GRDC (2004) Improving durum quality for market—receival point testing for vitreous kernel. Grains Research and Development Corporation, June 2004, http://finalreports.grdc.com.au/ADI00001

15 Watt S. (2016). Weed seed project aims to keep growers out of the woods. https://grdc.com.au/Media-Centre/Media-News/South/2016/03/Weed-seed-project-aims-to-keep-growers-out-of-the-woods

16 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

MORE INFORMATION

Windrow burning for weed control – WA fad or a viable option for the east?

IWM manual section on chaff carts

IWM manual section on bale direct systems

- Growers need to begin experimenting now on small areas to gain the experience needed to successfully implement the strategy. [17]

Narrow windrow burning is extremely effective – destroying up to 99 per cent of annual ryegrass and wild radish seeds – but it must be done properly. For ryegrass, a temperature of 400°C for at least 10 second is needed to destroy the seeds' viability. For wild radish, the temperature needs to be 500°C for at least 10 seconds. [18]

Chaff carts

Chaff carts are towed behind headers during harvest to collect the chaff fraction (Photo 3). Collected piles of chaff are then either burnt the following autumn or used as a source of stock feed.

Photo 3: *Chaff cart in action.*

Photo: A. Storrie

Chaff carts will collect and remove up to 85 per cent of annual ryegrass and wild radish seeds that pass through a header. Collected chaff must be managed to ensure the seeds are then removed from the cropping system. This can be done by burning in the following autumn or by removing the chaff from the paddock and using it as a livestock feed. [19]

Bale direct systems

The bale direct system uses a baler attached to the harvester to collect all chaff and straw material. This system requires a large baler to be attached to the back of the harvester. As well as removing weed seeds, the baled material has an economic value as a livestock feed source. (See http://www.glenvar.com/ for the story and development of header-towed bailing systems).

Harrington Seed Destructor

The HSD is the invention of Ray Harrington, a progressive farmer from Darkan, WA (Photo 4). Developed as a trail behind unit, the HSD system comprises a chaff processing cage mill, chaff and straw delivery systems. The retention of all harvest residues in the field reduces the loss and/or banding of nutrients and maintains all

17 Street M, Shepherd. (2013). Windrow burning for weed control – WA fad or a viable option for the east? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Windrow-burning-for-weed-control-WA-fad-or-viable-option-for-the-east

18 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

19 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

MORE INFORMATION

IWM manual section on Harrington seed destructor

VIDEOS

WATCH: Harvest weed seed control for the high rainfall zone.

WATCH: Harvest – the time to get on top of resistant weeds.

WATCH: A beginner's guide to harvest weed seed control.

organic matter to protect the soil from wind and water erosion, as well as reducing evaporation loss when compared with windrow burning, chaff carts and baling. [20]

The HSD, which renders seeds non-viable by collecting and impacting the chaff as it exits the harvester, can be 92 to 99% effective, depending on seed species. [21]

Photo 4: *Harrington seed destructor at work.*

Source: GRDC.

20 GRDC Integrated weed management hub. Section 6: Managing weeds at harvest. https://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

21 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

Storage

Key messages:

- Effective grain hygiene and aeration cooling can overcome 85% of pest problems.
- Monitor stored grain monthly for moisture, temperature and pests.
- Most markets want clean grain, free from insects and chemical residues. Check with potential buyers before treating with chemicals.
- Clean grain handling and storage equipment and dispose of or treat old, infested grain.
- Aeration cooling reduces insect breeding activity, but does not eliminate storage pests. Treatment may still be required, especially in the warmer period of the year.
- Fumigating with phosphine is only fully effective in pressure-tested storage that is gas-tight.

13.1 How to store product on-farm

Growers in the southern region are investing in on-farm storage for a range of reasons. In the eastern states, on-farm storage gives growers options into domestic and export markets, while in South Australia—where the majority of grain goes to bulk handlers—growers tend to set up storage to improve harvest management.

Growers might only plan to store grain on-farm for a short time, but markets can change, so investing in gas-tight sealable structures means you can treat pests reliably and safely and leave your business open to a range of markets.

Growers should approach storage as they would approach purchasing machinery:

- Growers spend a lot of time researching a header purchase to make sure it is fit-for-purpose. Grain storage can also be a significant investment, and a permanent one, so it pays to have a plan that adds value to your enterprise into the future.
- Agronomists tip: Decide what you want to achieve with storage, critique any existing infrastructure and be prepared for future changes. A good storage plan can remove a lot of stress at harvest—growers need a system that works so they capture a better return in their system. [1]

On-farm grain storage represents a significant investment. Many farms have older storage facilities that cannot be sealed for grain fumigation purposes, but replacing these facilities with sealable silos may not be an economically viable option.

A mixed storage strategy is a possible solution. The strategy is to purchase a small number of sealable silos and to use them to batch fumigate grain prior to sale.

There are several reasons why growers might consider storing grain on-farm, including:

- improving harvest logistics;
- taking advantage of higher grain prices some time after harvest;
- supplying a local market (e.g. feedlot, dairy etc.);
- avoiding high freight costs at peak time'
- value adding through cleaning, drying or blending grain;
- retaining planting seed; and
- potentially other site-specific benefits.

In most cases, for on-farm storage to be economical it will need to deliver on more than one of these benefits (Table 1). Under very favourable circumstances, grain

1 GRDC (2015) Ground cover issue 119—Grain storage. Extension tailored for regional challenges, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-119--Grain-storage/Extension-tailored-for-regional-challenges

storage facilities can pay for themselves within a few years, but it is also possible for an investment in on-farm storage to be very unprofitable. The grain storage cost-benefit analysis template is very useful step in the decision making process to test the viability of grain storage on your farm. [2]

Table 1: *Advantages and disadvantages of grain storage options.*

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	• Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects • Easily aerated with fans • Fabricated on-site or off-site and transported • Capacity from 15 t up to 3000 t • Up to 25 years-plus service life • Simple in-loading and out-loading • Easily administered hygiene (cone base particularly) • Can be used multiple times in a season	• Requires foundation to be constructed • Relatively high initial investment required • Seals must be regularly maintained • Access requires safety equipment and infrastructure • Requires an annual test to check gas-tight sealing
Non-sealed silo	• Easily aerated • 7–10% cheaper than sealed silos • Capacity from 15 t up to 3000 t • Up to 25 years-plus service life • Can be used multiple times in a season	• Requires foundation to be constructed • Silo cannot be used for fumigation—see phosphine label • Insect control options limited to protectants in eastern states and dryacide in Western Australia • Access requires safety equipment and infrastructure

2 GRDC (2015) Grain storage strategies in the northern region, https://grdc.com.au/Media-Centre/Hot-Topics/Grain-storage-strategies-in-the-northern-region

Storage type	Advantages	Disadvantages
Grain storage bags	• Low initial cost • Can be laid on a prepared pad in the paddock • Provide harvest logistics support • Can provide segregation options • Are all ground operated • Can accommodate high yielding seasons	• Requires purchase or lease of loader and unloader • Increased risk of damage beyond short term storage (typically three months) • Limited insect control options; fumigation only possible under specific protocols • Requires regular inspection and maintenance which needs to be budgeted for • Aeration of grain in bags currently limited to research trials only • Must be fenced off • Prone to attack by mice, birds, foxes etc. • Limited wet weather access if stored in paddock • Need to dispose of bag after use • Single-use only
Grain storage sheds	• Can be used for dual purposes • 30 year-plus service life • Low cost per stored tonne	• Aeration systems require specific design • Risk of contamination from dual purpose use • Difficult to seal for fumigation • Vermin control is difficult • Limited insect control options without sealing • Difficult to unload

Source: Kondinin Group

MORE INFORMATION

Benefits flow from on-farm storage in the Mallee.

GRDC Retaining seed factsheet.

13.1.1 Storing durum

Storage conditions determine the safe storage period for any grain. Up until 2011 there were no safe storage guidelines for durum wheat, despite the fact that it is more susceptible to spoilage than other wheat classes. A study conducted at the University of Manitoba, Canada, in 2011 studied the rates of deterioration of durum wheat samples at various moisture contents and temperatures to develop guidelines. Samples with 15, 16, 17, 18, 19 and 20% initial moisture content (wet basis [wb]) were stored at 10, 20, 30 and 40°C for 12 weeks. Key findings included:

- There was no quality loss of durum wheat when stored at low moisture (<15% wb) and low temperatures (<20°C).
- High moisture (>16% wb) grains should be dried in a week to prevent deterioration.
- Fungal growth increased with an increase in moisture content, storage temperature and time.
- Time available for corrective actions decreased with increased moisture content and temperature. [3]

Utilise this On-farm storage checklist to optimise grain storage potential.

VIDEOS

WATCH: Over the Fence: On-farm storage pays in wet harvest.

3 U Nithya, V Chelladurai, DS Jayas, NDG White (2011). Safe storage guidelines for durum wheat. Journal of Stored Products Research, 47(4), 328–333, http://dx.doi.org/10.1016/j.jspr.2011.05.005.

13.1.2 Silos

To minimise insect attack, the grain should be stored at less than 10% moisture, preferably in sealed silos (Photo 1). Treat the grain as it enters the silo and then check regularly (2–3 months) for reinfestation by grain insects.

PHOTOS: CHRIS WARRICK, KONDININ GROUP

Photo 1: *When using on-farm silos it is important to pressure test all silos, even those that are labeled as "sealed".*

Source: GRDC

Sealed silos offer a more permanent grain storage option than grain storage bags. Depending on the amount of storage required, they will have a higher initial capital cost than grain storage bags and are depreciated over a longer time frame than the machinery required for the grain bags. In a silo grain storage system as stored tonnage increases the capital cost of storage increases.

Potential advantages of using sealed grain silos as a method for grain storage include improved harvest management, reduced harvest stress, reduced harvest freight requirements, minimal insecticide exposure and the opportunity to segregate and blend grain.

Potential disadvantages of using sealed grain silos as a method for grain storage include the initial capital outlay, the outlay required to meet occupational health and safety requirements, the additional on-farm handling required and the additional site maintenance requirements. [4]

Pressure testing

- A silo sold as a "sealed silo" needs to be pressure tested to be sure it's gas-tight.
- It is strongly recommended that growers ask the manufacturer or reseller to quote the AS2628 on the invoice as a means of legal reference to the quality of the silo being paid for.
- Pressure test sealed silos upon erection, annually and before fumigating with a five-minute half-life pressure test.
- Maintenance is the key to ensuring a silo purchased as sealable can be sealed and gas-tight.

A silo is only truly sealed if it passes a five-minute half-life pressure test according to the Australian Standard AS2628. Often silos are sold as sealed but are not gas-tight, rendering them unsuitable for fumigation.

4 J Francis (2006) An analysis of grain storage bags, sealed grain silos and warehousing for storing grain, https://grdc.com.au/uploads/documents/Final%20report%20Grain%20Storage%20Bags%2021%20Jul%20061.pdf

MORE INFORMATION

GRDC Pressure testing sealable silos factsheet

GRDC Silo buyer's guide

VIDEOS

WATCH: Pressure testing sealed silos.

Even if a silo is sold as "sealed" it is not sealed until it is proven gas-tight with a pressure test.

The term "sealed" has been used loosely during the past and in fact some silos may not have been gas-tight from the day they were constructed.

However, even a silo that was gas-tight to the Australian Standard on construction will deteriorate over time, so needs annual maintenance to remain gas-tight.

Why do I need to do a pressure test?

In order to kill grain pests at all stages of their life cycle (egg, larvae, pupae, adult) phosphine gas concentration levels need to reach and remain at 300 parts per million (ppm) for 7 days or 200 ppm for 10 days.

The importance of a gas-tight silo

The Kondinin Group 2009 National Agricultural survey 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 five years. A Grains Research and Development Corporation survey during 2010 revealed that only 36% of growers using phosphine applied it correctly, in a gas-tight, sealed silo (Figure 1). Research shows that fumigating in a storage that does not meet the industry standard "silo pressure test" does not achieve a high enough concentration of fumigant for a long enough period to kill pests at all life-cycle stages (Figure 2). For effective phosphine fumigation, a minimum of 300 ppm gas concentration for seven days or 200 ppm for ten days is required. Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks. The rest of the silo also suffers from reduced gas levels. [5]

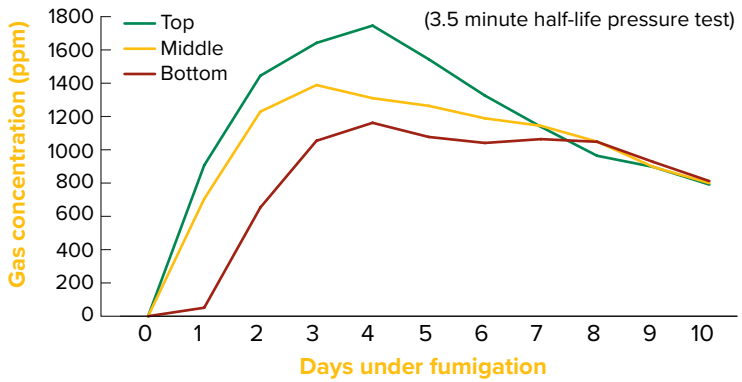


Figure 1: *Gas concentration in gas-tight silo.*

Source: GRDC

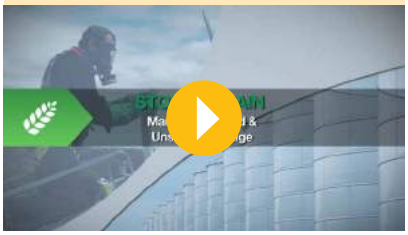
5 P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. GRDC Fact Sheet, September 2010, https://www.grdc.com.au/~/media/0218DA4A22264A31B6202718043758DE.pdf

MORE INFORMATION

Fumigating with phosphine, other fumigants and controlled atmospheres

VIDEOS

WATCH: Stored grain: Managing sealed and unsealed storage



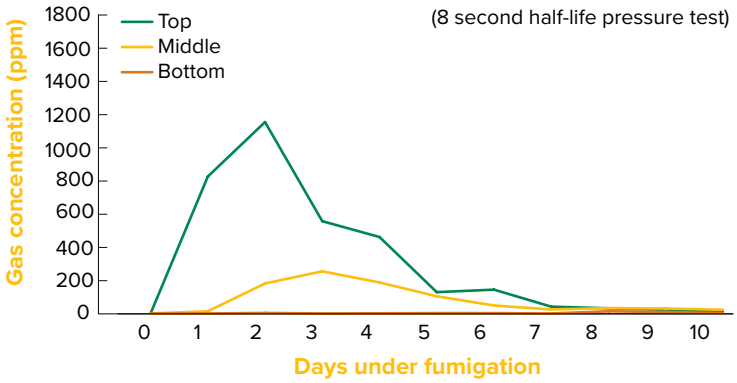


Figure 2: *Gas concentration in non-gas-tight silo.*

Source: GRDC

It is recommended to pressure test silos that are sealable once a year to check for damaged seals on openings. Storages must be able to be sealed properly to ensure effective fumigation.

There is no compulsory manufacturing standard for sealed silos in Australia. A voluntary industry standard was adopted in 2010. Watch this GRDC Ground Cover TV clip to find out more.

13.1.3 Grain bags

Grain storage bags are relatively new technology offering a low cost alternative for temporary storage of grain to permanent grain storage structures on-farm such as silos. Grain storage bags are made of multilayer polyethylene material, similar to that used in silage fodder systems. Bags typically store between 200 and 220 tonnes of wheat and are filled and emptied using specialised machinery (Photo 2). The bags are sealed after filling producing a relatively airtight environment which, under favourable storage conditions, protects grain from insect damage without the use of insecticides.

Potential advantages of using grain storage bags as a method for grain storage include the low capital set up costs, improved harvest management, less harvest stress, reduced harvest freight requirements, minimal cost in occupational health and safety (OH&S) requirements, reduced grain insecticide requirements and the opportunity to segregate and blend grain.

Potential disadvantages of using grain storage bags as a method for grain storage include the requirement for disposal of used bags, the period of storage before bag deterioration and the management necessary to ensure bag integrity. Another potential disadvantage of this system, when compared to permanent structures, is that once the storage period is complete there is no asset value in the storage system other than the bagging machinery. [6]

6 J Francis (2006) An analysis of grain storage bags, sealed grain silos and warehousing for storing grain, https://grdc.com.au/uploads/documents/Final%20report%20Grain%20Storage%20Bags%2021%20Jul%20061.pdf

VIDEOS

WATCH: Grain bags best practice.

WATCH: Extension Files: Grain bags—a grower's perspective

Photo 2: *A 100 m bag can be filled in 30 minutes with a constant supply of grain.*

Source: StarTribune

13.1.4 Monitoring stored grain

Monitoring grain temperature and moisture content:

- Pests and grain moulds thrive in warm, moist conditions. Monitor grain moisture content and temperature to prevent storage problems.
- Use a grain temperature probe to check storage conditions and aeration performance (Photo 3).
- When checking grain, smell air at the top of storages for signs of high grain moisture or mould problems.
- Check germination and vigour of planting seed in storage.
- Aeration fans can be used to cool and dry grain to reduce storage environment problems.

It is vital to monitor grain moisture content to prevent pests and grain moulds from thriving. [7]

Photo 3: *Monitor moisture and temperature using a digital probe from both the top and the bottom of silos, if safe to do so.*

Source: Plant Health Australia

7 Plant Health Australia (2015) Monitoring stored grain on farm, http://www.planthealthaustralia.com.au/wp-content/uploads/2015/11/Monitoring-stored-grain-on-farm.pdf

13.1.5 Grain storage—get the economics right

As growers continue to expand their on-farm grain storage, the question of economic viability gains significance. There are many examples of growers investing in on-farm grain storage and paying for it in one or two years because they struck the market at the right time, but are these examples enough to justify greater expansion of on-farm grain storage?

The grain storage extension team conduct approximately 100 grower workshops every year, Australia wide, and it is evident that no two growers use on-farm storage in the exact same way. Like many economic comparisons in farming, the viability of grain storage is different for each grower. Depending on the business's operating style, the location, the resources and the most limiting factor to increase profit; grain storage may or may not be the next best investment. For this reason, everyone needs to do a simple cost benefit analysis for their own operation.

Comparing on-farm grain storage

To make a sound financial decision, we need to compare the expected returns from grain storage versus expected returns from other farm business investments—such as more land, a chaser bin, a wider boomspray, a second truck or paying off debt. The other comparison is to determine if we can store grain on-farm cheaper than paying a bulk handler to store it for us.

Calculating the costs and benefits of on-farm storage will enable a return-on investment (ROI) figure, which can be compared with other investment choices and a total cost of storage to compare to the bulk handlers.

Cheapest form of storage

The key to a useful cost–benefit analysis is identifying which financial benefits to plan for and costing an appropriate storage to suit that plan. People often ask, "what's the cheapest form of storage?" The answer is the storage that suits the planned benefits. Short-term storage for harvest logistics or freight advantages can be suited to grain bags or bunkers. If flexibility is required for longer term storage, gas-tight, sealable silos with aeration cooling allow quality control and insect control.

Benefits

To compare the benefits and costs in the same form, work everything out on a basis of dollars per tonne. On the benefit side, the majority of growers will require multiple financial gains for storing grain to make money out of it. These might include harvest logistics or timeliness, market premiums, freight savings or cleaning, blending, or drying grain to add value.

Costs

The costs of grain storage can be broken down into fixed and variable. The fixed costs are those that don't change from year to year and have to be covered over the life of the storage. Examples are depreciation and the opportunity or interest cost on the capital. The variable costs are all those that vary with the amount of grain stored and the length of time it is stored for. Interestingly, the costs of good hygiene, aeration cooling and monitoring are relatively low compared to the potential impact they can have on maintaining grain quality. One of the most significant variable costs, and one that is often overlooked, is the opportunity cost of the stored grain. That is the cost of having grain in storage rather than having the money in the bank paying off an overdraft or a term loan.

The result

While it is difficult to put an exact dollar value on each of the potential benefits and costs, a calculated estimate will determine if it is worth a more thorough investigation. If we compare the investment of on-farm grain storage to other investments and the result is similar, then we can revisit the numbers and work on increasing their accuracy. If the return is not even in the ball park, we have potentially avoided a

costly mistake. On the contrary, if after checking our numbers the return is favourable, we can proceed with the investment confidently.

Summary

Unlike a machinery purchase, grain storage is a long-term investment that cannot be easily changed or sold. Based on what the grain storage extension team is seeing around Australia, the growers who are taking a planned approach to on-farm grain storage and doing it well are being rewarded. Grain buyers are seeking out growers who have a well-designed storage system that can deliver insect free, quality grain without delay.

Table 2 is a tool that can be used to figure out the likely economic result of on-farm grain storage for each individual business. Each column can be used to compare various storage options including type of storage, length of time held or paying a bulk handler. [8]

Table 2: *Cost-benefit template for grain storage.*

Financial gains from storage		Example $/t
Harvest logistics/ timeliness	Grain price x reduction in value after damage % x probability of damage %	$16
Marketing	Post harvest grain price - harvest grain price	
Freight	Peak rate $/t - post harvest rate $/t	$20
Cleaning to improve grade	Clean grain price - original grain price - cleaning costs - shrinkage	
Blending to lift average grade	Blended price - ((low grade price x %mix) + (high grade price x %mix))	
Total benefits	Sum of benefits	$36.20
Capital cost	Infrastructure cost / storage capacity	$155
Fixed costs		
Annualised depreciation cost	Capital cost $/t / expected life storage e.g. 25 yrs	$6.20
Opportunity cost on capital	Capital cost $/t x opportunity or interest rate e.g. 8% / 2	$6.20
Total fixed costs	Sum of fixed costs	$12.40
Variable costs		
Storage hygiene	(Labour rate $/hr x time to clean hrs / storage capacity) + structural treatment	$0.23
Aeration cooling	Indicatively 23c for the first 8 days then 18c per month / t	$0.91
Repairs and maintenance	Estimate, e.g. capital cost $/t x 1%	$1.51
Inload/outload time and fuel	Labour rate $/hr / 60 minutes / auger rate t/m x 3	$0.88
Time to monitor and manage	Labour rate $/hr x total time to manage hrs / storage capacity	$0.24
Opportunity cost of stored grain	Grain price x opportunity interest rate e.g. 8% / 12 x No. months stored	$7.20
Insect treatment cost	Treatment cost $/t x No. of treatments	$0.35
Cost of bags or bunker trap	Price of bag / bag capacity tonne	

MORE INFORMATION

GRDC Economics of on-farm grain storage, cost benefit analysis

Economics of on-farm grain storage: a grains industry guide

8 C Warrick (2016) GRDC Update Papers: Grain storage—get the economics right. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/09/Grain-storage-get-the-economics-right

Financial gains from storage		Example $/t
Total variable costs	Sum of variable costs	$11.32
Total cost of storage	Total fixed costs + total variable costs	$23.72
Profit/Loss on storage	Total benefits - total costs of storage	$12.48
Return on investment	Profit or loss / capital cost x 100	8.1%

Source: GRDC

13.2 Stored grain pests

Key points

- Effective grain hygiene and aeration cooling can overcome 85% of pest problems.
- When fumigation is needed it must be carried out in pressure-tested, sealed silos.
- Monitor stored grain monthly for moisture, temperature and pests.

Prevention is better than cure

The combination of meticulous grain hygiene plus well-managed aeration cooling generally overcomes 85% of storage pest problems.

For grain storage, three key factors provide significant gains for both grain storage pest control and grain quality: hygiene, aeration cooling and correct fumigation. [9]

Common species

The most common insect pests of stored cereal grains in Australia are (Figure 3):

- Weevils *(Sitophilus spp.)*. Rice weevil is the most common weevil in cereals in Australia.
- Lesser Grain Borer *(Rhyzopertha dominica)*.
- Rust Red Flour Beetle *(Tribolium spp.)*.
- Sawtooth Grain Beetle *(Oryzaephilus spp.)*.
- Flat Grain Beetle *(Cryptolestes spp.)*.
- Indian Meal Moth *(Plodia interpunctella)*.
- Angoumois Grain Moth *(Sitotroga cerealella)*.

Another dozen or so beetles, psocids (booklice) and mites are sometimes present as pests in stored cereal grain.

9 GRDC Stored Grain Information Hub. Northern and Southern Regions Grain Storage Pest control guide, http://storedgrain.com.au/pest-control-guide-ns/

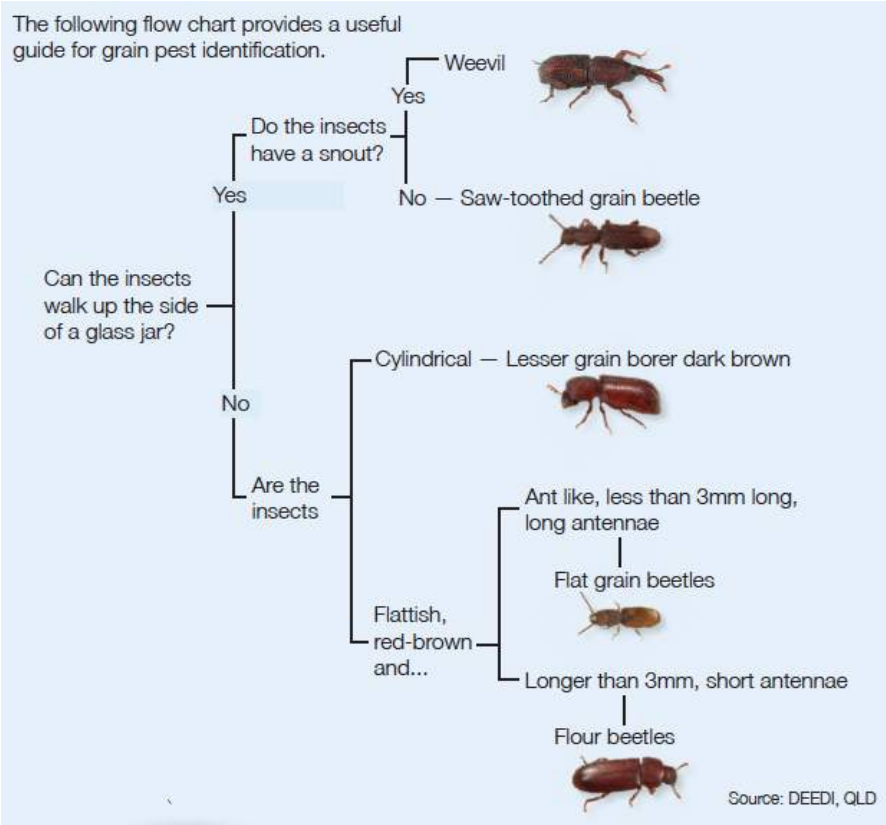


Figure 3: *Identification of common pests of stored grain.*

Source: GRDC

Why identify stored insect grain pests?

Most insect control methods for stored grain work against all species. So you don't need to identify the storage pests to make decisions about most control methods. But if you intend spraying grain with insecticides you may need to know which species are present if:

- A previous application has failed and you want to know whether resistance was the reason—if more than one species survived, resistance is unlikely to be the cause.
- You intend to use a residual protectant to treat infested grain—pyrimiphos-methyl, fenitrothion and chlorpyrifos-methyl are ineffective against lesser grain borer, and pyrimiphos-methyl and fenitrothion are generally ineffective against sawtoothed grain beetle.
- You intend to use dichlorvos to treat infested grain—if lesser grain borer is present you need to apply the higher dose rate. This then increases the withholding period before grain can be marketed from 7–28 days.

MORE INFORMATION

Stored grain pests identification

13.2.1 Monitoring grain for pests

Damage by grain insect pests often goes unnoticed until the grain is removed from storage. Regular monitoring will help to ensure that grain quality is maintained.

- Sample each grain storage at least monthly. During warmer periods of the year, fortnightly sampling is recommended.
- Take samples from the top and bottom of grain stores and sieve (using 2 mm mesh) onto a white tray to separate any insects (Photo 4).
- Hold tray in the sunlight for 10–20 seconds to trigger movement of any insects, making them easier to see. Use a magnifying glass to identify pests.

MORE INFORMATION

GRDC Stored grain pests: the back pocket guide

Monitoring stored grain on-farm.

VIDEOS

WATCH: GCTV2: Grain Storage Insect ID

- Grain probes or pitfall traps should also be used to check for insects. These traps are left in the grain during storage and are often able to detect the start of an infestation.
- Push probe/trap into the grain surface and pull up for inspection fortnightly/monthly. Place 1–2 traps in the top of a silo or several traps in a grain shed.
- Be sure to check grain 3 weeks prior to sale to allow time for treatment if required. [10]

Photo 4: *A 2 mm mesh sieve will separate insects from grain.*

Source: Plant Health Australia

13.2.2 Hygiene

Key points

- Effective grain hygiene requires complete removal of all waste grain from storages and equipment.
- Be meticulous with grain hygiene—pests only need a small amount of grain for survival.

A bag of infested grain can produce more than one million insects during a year, which can walk and fly to other grain storages where they will start new infestations. Meticulous grain hygiene involves removing any grain that can harbour pests and allow them to breed. It also includes regular inspection of seed and stockfeed grain so that any pest infestations can be controlled before pests spread.

Where to clean

Removing an environment for pests to live and breed in is the basis of grain hygiene, which includes all grain handling equipment and storages. Grain pests live in dark, sheltered areas and breed best in warm conditions.

Common places where pests are found include:

- Empty silos and grain storages.
- Aeration ducts, augers and conveyers.
- Harvesters, field bins and chaser bins.
- Left-over bags of grain trucks.

10 Plant Health Australia (2015) Monitoring stored grain on-farm, http://www.planthealthaustralia.com.au/wp-content/uploads/2015/11/Monitoring-stored-grain-on-farm.pdf

- Spilt grain around grain storages.
- Equipment and rubbish around storages.
- Seed grain.
- Stockfeed grain.

Successful grain hygiene involves cleaning all areas where grain gets trapped in storages and equipment (Photo 5). Grain pests can survive in a tiny amount of grain, so any parcel of fresh grain through the machine or storage becomes infested.

Photo 5: *Grain left in trucks is an ideal place for grain pests to breed. Keep trucks, field bins and chaser bins clean.*

Source: GRDC

When to clean

Straight after harvest is the best time to clean grain handling equipment and storages, before they become infested with pests. One trial revealed more than 1,000 lesser grain borers in the first 40 litres of grain through a harvester at the start of harvest, which was considered reasonably clean at the end of the previous season. Discarding the first few bags of grain at the start of the next harvest is also a good idea. Further studies revealed insects are least mobile during the colder months of the year. Cleaning around silos in July–August can reduce insect numbers before they become mobile.

How to clean

The better the cleaning job, the less chance of pests harbouring. The best ways to get rid of all grain residues use a combination of:

- Sweeping
- Vacuuming
- Compressed air
- Blow/vacuum guns
- Pressure washers
- Fire-fighting hoses

Using a broom or compressed air gets rid of most grain residues, and a follow-up wash-down removes grain and dust left in crevices and hard-to-reach spots (Photo 6). Choose a warm, dry day to wash storages and equipment so that it dries out quickly, to prevent rusting. When inspecting empty storages, look for ways to make the structures easier to keep clean. Seal or fill any cracks and crevices to prevent grain lodging and insects harbouring. Bags of leftover grain lying around storages and in sheds create a perfect harbour and breeding ground for storage pests.

After collecting spilt grain and residues, dispose of them well away from any grain storage areas.

Photo 6: *Clean silos, including the silo wall, with air or water to provide a residue-free surface to apply structural treatments.*

Source: GRDC

The process of cleaning on-farm storages and handling equipment should start with the physical removal, blowing and/or hosing out of all residues. Once the structure is clean and dry, consider the application of DE as a structural treatment. See Section 13.2.4 Structural treatments for more information.

A concrete slab underneath silos makes cleaning much easier (Photo 7).

Agronomist's view

Photo 7: *A concrete slab underneath silos makes cleaning up spilled grain much easier.*

Source: GRDC

VIDEOS

WATCH: Grain Silo Hygiene.

13.2.3 Aeration cooling for pest control

While adult insects can still survive at low temperatures, most young storage pests stop developing at temperatures below 18–20°C (see Table 3).

At temperatures below 15°C the common rice weevil stops developing.

At low temperatures insect pest life cycles (egg, larvae, pupae and adult) are lengthened from the typical four weeks at warm temperatures (30–35°C) to 12–17 weeks at cooler temperatures (20–23°C).

Table 3: *The effect of grain temperature on insects and mould.*

Grain temp (°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 are active	13–18
20–25	Mould development is limited	10–13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group in GRDC

For more information, see Section 13.3.2 Aeration cooling below

MORE INFORMATION

GRDC fact sheet, Aeration cooling for pest control

13.2.4 Structural treatments

Key points

- Structural treatments, such as diatomaceous earth (DE), can be used on storages and equipment to protect against grain pests.
- Check delivery requirements before using chemical treatments.

Using diatomaceous earth (DE) as a structural treatment is possible. Diatomaceous earth is an amorphous silica commercially known as Dryacide® that acts by absorbing the insect's cuticle or protective waxy exterior, causing death by desiccation. If applied correctly with complete coverage in a dry environment, DE can provide up to 12 months of protection for storages and equipment.

If unsure, check with the grain buyer before using any product that will come in contact with the stored grain. [11]

MORE INFORMATION

Hygiene and structural treatments for grain storages.

Application

Inert dust requires a moving air stream to direct it onto the surface being treated; alternatively, it can be mixed into a slurry with water and sprayed onto the surface. See label directions. Throwing dust into silos by hand will not achieve an even coverage, so will not be effective. For very small grain silos and bins, a hand operated duster, such as a bellows duster, is suitable. Larger silos and storages require a powered duster operated by compressed air or a fan. If compressed air is available, it is the most economical and suitable option for on-farm use, connected to a venturi duster such as the Blovac BV-22 gun (Photo 8).

11 GRDC Stored Grain information hub. Storing Pulses, http://storedgrain.com.au/wp-content/uploads/2014/09/GSFS-8_Storing-Pulses-July14.pdf

Photo 8: *A blow/vac or air venture gun is the best applicator for inert dusts. Aim for an event coat of diatomaceous earth across the roof, walls and base.*

Photo: C Warrick, Proadvice

The application rate is calculated at 2 g/m^2 surface area treated. Although inert, breathing in excessive amounts of dust is not ideal, so use a disposable dust mask and goggles during application (Table 4).

Silo application

Apply inert dust in silos, starting at the top (if safe) by coating the inside of the roof, then working your way down the silo walls, finishing by pointing the stream at the bottom of the silo (Table 4). If silos are fitted with aeration systems, distribute the inert dust into the ducting without getting it into the motor, where it could cause damage. [12]

Table 4: *Inert dust (diatomaceous earth) application guide.*

Storage capacity (t)	Dust quantity (kg)
20	0.12
56	0.25
112	0.42
224	0.60
450	1.00
900	1.70
1,800	2.60

Source: GRDC

13.2.5 Fumigation

There are a number of chemical control options for the control of grain pests in stored cereals (Table 5).

MORE INFORMATION

GRDC Grain Storage Fact Sheet: Hygiene and Structural Treatment for Grain Storages.

VIDEOS

WATCH: Applying diatomaceous earth dust.

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

Table 5: *Resistance and efficacy guide for stored grain insects. Before applying, check with your grain buyers/bulk handlers and read labels carefully.*

Treatment and example product	WHP	Lesser grain borer	Rust-red flour beetle	Rice weevil	Saw-toothed grain beetle	Flat grain beetle	Psocids (booklice)	Structural treatments
Grain disinfestants—used on infested grain to control full life cycle (adults, eggs, larvae, pupae)								
Phosphine (Fumitoxin®)[1,3] when used in gas-tight, sealable stores	2							
Sulfuryl fluoride (ProFume®)[10]	1							
Grain protectants—applied postharvest. Poor adult control if applied to infested grain								
Pirimiphos-methyl (Actellic 900®)	nil[2]							
Fenitrothion (Fenitrothion 1000®)[4, 7]	1–90							
Chlorpyrifos-methyl (Reldan Grain Protector®)[5]	Nil[2]							
'Combined products' (Reldan Plus IGR Grain Protector)	Nil[2]							
Deltamethrin (K-Obiol®)[10]	Nil[2]							
Spinosad and Chlorpyrifos-methyl (eg Conserve On-Form™)[9]								
Diatomaceous earth, amorphous silica—effective internal structural treatment for storages and equipment. Specific-use grain treatments								
Diatomaceous earth, amorphous silica (Dryacide®)[8]	Nil[2]							

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

1 Unlikely to be effective in unsealed sites, causing resistance, see label for definitions
2 When used as directed on label
3 Total of (exposure + ventilation + withholding) = 10 to 27 days
4 Nufarm label only
5 Stored grains except malting barley and rice/ stored lupins registration for Victoria only/ not on stored maize destined for export
6 When applied as directed, do not move treated grain for 24 hours
7 Periods of 6–9 months storage including mixture in adulticide (e.g. Fenitrothion at label rate)
8 Do not use on stored maize destined for export, or on grain delivered to bulk-handling authorities
9 Dichlorvos 500 g/L registration only
10 Restricted to licensed fumigators or approved users
11 Restriced 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

Source: http://storedgrain.com.au/pest-control-guide-ns/

Fumigation with phosphine is a common component of many integrated pest control strategies (Photo 9).

Taking fumigation shortcuts may kill enough adult insects in grain so it passes delivery standards, but the repercussions of such practices are detrimental to the grains industry.

Poor fumigation techniques fail to kill pests at all life cycle stages, so while some adults may die, grain will soon be reinfested again as soon as larvae and eggs develop.

What's worse, every time a poor fumigation is carried out, insects with some resistance survive, making the chemical less effective in the future.

VIDEOS

WATCH: GCTV Stored Grain. Fumigation recirculation.

WATCH: GCTV Stored Grain: Phosphine Dose Rates.

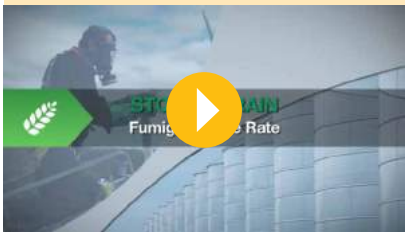


Photo 9: *Phosphine is widely accepted as having no residue issues.*

Photo: QDAFF

While phosphine has some resistance issues, it is widely accepted as having no residue issues for grain. The grain industry has adopted a voluntary strategy to manage the build-up of phosphine resistance in pests. Its core recommendations are to limit the number of conventional phosphine fumigations on undisturbed grain to three per year, and to employ a break strategy. [13]

Phosphine application

For effective phosphine fumigation, a minimum of 300 parts per million (ppm) gas concentration for seven days or 200 ppm for 10 days is required. Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks. The rest of the silo also suffers from reduced gas levels.

Achieve effective fumigation by placing the correct phosphine rates (as directed on the label) onto a tray and hanging it in the top of a pressure-tested, sealed silo or into a ground level application system if the silo is fitted with recirculation.

After fumigation, ventilate grain for a minimum of one day with aeration fans running, or five days if no fans are fitted.

A minimum withholding period of two days is required after ventilation before grain can be used for human consumption or stock feed.

The total time needed for fumigating is 10–17 days.

As a general rule, only keep a silo sealed while carrying out the fumigation (for example, one to two weeks).

After fumigation has been completed, return to aeration cooling to hold the stored grain at a suitable temperature level.

Handle with care

Phosphine is a highly toxic gas with potentially fatal consequences if handled incorrectly. As a minimum requirement, the label directs the use of cotton overalls buttoned at the neck and wrist, eye protection, elbow-length PVC gloves and a breathing respirator with combined dust and gas cartridge.

13 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry, Cooperative Research Centre for National Plant Biosecurity, http://www.graintrade.org.au/sites/default/files/file/NWPGP/Phosphine%20Resistance%20Strategy.pdf

MORE INFORMATION

Grain fumigation—a guide

Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once. A Grains Industry Guide

Where to apply

Arrange the tablets where as much surface area as possible is exposed to air, so the gas can disperse freely throughout the grain stack. Spread phosphine tablets evenly across trays before hanging them in the head space or placing them level on the grain surface inside a gas-tight, sealed silo. Hang bag chains in the head space or roll out flat on the top of the grain so air can freely pass around them as the gas dissipates. Bottom-application facilities must have a passive or active air circulation system to carry the phosphine gas out of the confined space as it evolves. Without air movement, phosphine can reach explosive levels if left to evolve in a confined space.

Time to kill

To control pests at all life stages and prevent insect resistance, phosphine gas concentration needs to reach 300 ppm for seven days (when grain is above 25°C) or 200 ppm for 10 days (between 15–25°C). Insect activity is slower in cooler grain temperatures so require longer exposer to the gas to receive a lethal dose. [14]

Non-chemical treatment options include:

- Carbon dioxide: Treatment with CO_2 involves displacing the oxygen inside a gas-tight silo with CO_2, which creates a toxic atmosphere to grain pests. To achieve a complete kill of all the main grain pests at all life stages, CO_2 must be retained at a minimum concentration of 35% for 15 days.
- Nitrogen: Grain stored under N_2 provides insect control and quality preservation without chemicals. It is safe to use and environmentally acceptable, and the main operating cost is the capital cost of equipment and electricity. It also produces no residues, so grains can be traded at any time, unlike chemical fumigants that have withholding periods. Insect control with N_2 involves a process using pressure swinging adsorption (PSA) technology, modifying the atmosphere within the grain storage to remove everything except N_2, starving the pests of oxygen. [15]

13.3 Aeration during storage

13.3.1 Dealing with high moisture grain

Key points

- Deal with high-moisture grain promptly.
- Monitoring grain moisture and temperature regularly (daily) will enable early detection of mould and insect development.
- Aeration drying requires airflow rates in excess of 15 L/s/t.
- Dedicated batch or continuous flow dryers are a more reliable way to dry grain than aeration drying in less-than-ideal ambient conditions.

A Department of Employment, Economic Development and Innovation (DEEDI) trial revealed that high-moisture grain generates heat when put into a confined storage, such as a silo.

Wheat at 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 two days reached 46°C, providing ideal conditions for mould growth and grain damage (Figure 4). Grain that is over the standard safe storage moisture content of 12.5% can be dealt with by:

- Blending: mixing high-moisture grain with low-moisture grain, then aerate.
- Aeration cooling: grain of moderate moisture, up to 15% moisture content, can be held for a short term under aeration cooling until drying equipment is available.

14 GRDC Stored Grain Information Hub. Grain Fumigation—A guide, http://storedgrain.com.au/fumigation-guide/

15 C Warrick (2012) Fumigating with phosphine, other fumigants and controlled atmospheres: Do It right—(2012) Fumigating with phosphine, other fumigants and controlled atmosphhttp://www.grdc.com.au/~/media/5EC5D830E7BF4976AD591D2C03797906.pdf

- Aeration drying" large volumes of air force a drying front through the grain in storage and slowly removes moisture. Supplementary heating can be added.
- Continuous flow drying: grain is transferred through a dryer, which uses a high volume of heated air to pass through the continual flow of grain.
- Batch drying: usually a transportable trailer drying 10–20 tonnes of grain at a time with a high volume of heated air, which passes through the grain and out perforated walls.

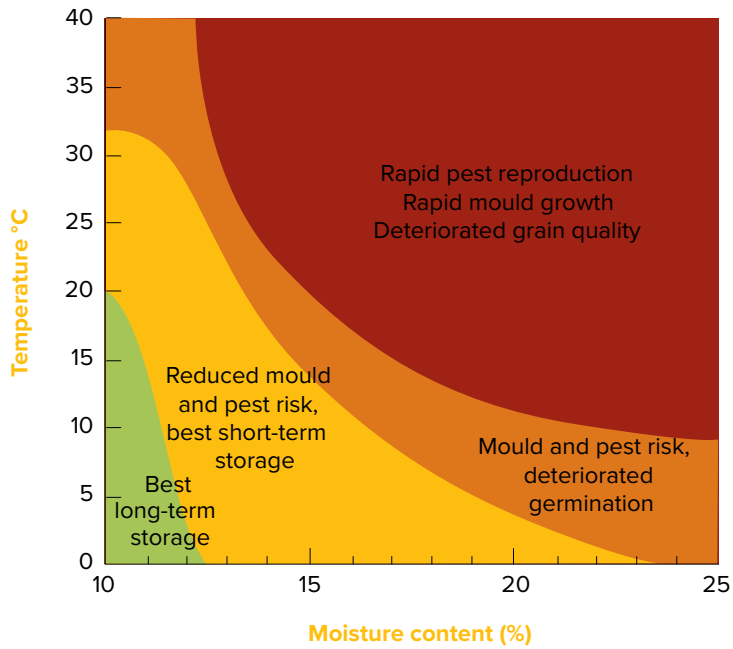


Figure 4: *Effects of Temperature and moisture on pest risk in stored grain.*

Source: CSIRO Ecosystems Sciences in GRDC

13.3.2 Aeration cooling

Key points

- Grain temperatures below 20°C significantly reduce mould and insect development.
- Reducing grain temperature with aeration cooling protects seed viability.
- Controlling aeration cooling is a three-stage process—continual, rapid and then maintenance.
- Stop aeration if ambient, relative humidity exceeds 85%.
- Automatic grain aeration controllers that select optimum fan run times provide the most reliable results.

Aeration cooling can be used to reduce the risk of mould and insect development for a month or two until drying equipment is available to dry grain down to a safe level for long-term storage or deliver. In most circumstances, grain can be stored at up to 14–15% moisture content safely with aeration cooling fans running continuously, delivering at least 2–3 L/s/t. It is important to keep fans running continuously for the entire period, only stopping them if the ambient relative humidity is above 85% for more than about 12 hours, to avoid wetting the grain further.

Blending

Blending is the principle of mixing slightly over-moist grain with lower-moisture grain to achieve an average moisture content below the ideal 12.5% moisture content. Successful for grain moisture content levels up to 13.5%, blending can be an inexpensive way of dealing with wet grain, providing the infrastructure is available. Aeration cooling does allow blending in layers but if aeration cooling is not available blending must be evenly distributed (see Figure 5). [16]

MORE INFORMATION

GRDC Aerating Stored Grain—Industry Guide

VIDEOS

WATCH: Grain Storage Cooling Aeration

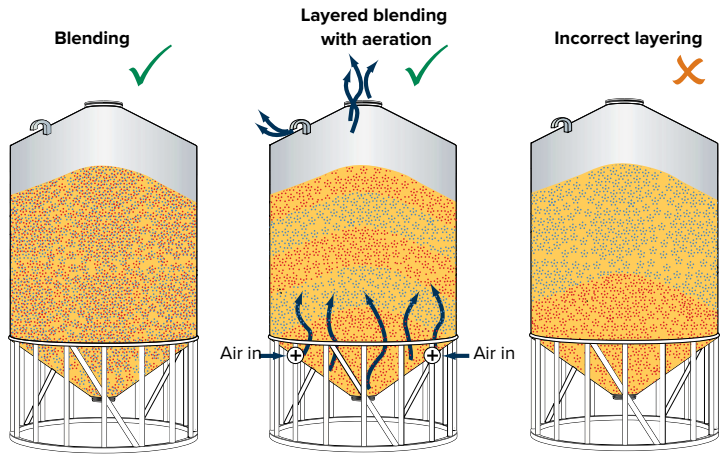


Figure 5: *Diagram demonstrating the correct practices for blending.*

Source: Kondinin Group, in GRDC

Seed viability

Research trials reveal that wheat at 12% moisture content stored for six months at 30–35°C (unaerated grain temperature) will have reduced germination percentage and seedling vigour.

13.3.3 Aeration drying

Aeration drying relies on a high air volume and is usually done in a purpose-built drying silo or a partly filled silo with high-capacity aeration fans. Aeration drying is a slow process and relies on four keys:

- High airflow rates.
- Well-designed ducting for even airflow through the grain.
- Exhaust vents in the silo roof.
- Warm, dry weather conditions.

It is important to seek reliable advice on equipment requirements and correct management of fan run times, otherwise there is a high risk of damaging grain quality.

High airflow for drying

Unlike aeration cooling, aeration drying requires high airflow, in excess of 15 l/s/t, to move drying fronts quickly through the whole grain profile and depth and carry moisture out of the grain bulk. As air passes through the grain, it collects moisture and forms a drying front. If airflow is too low, the drying front will take too long to reach the top of the grain stack—often referred to as a "stalled drying front". Providing the storage has sufficient aeration ducting, a drying front can pass through a shallow stack of grain much faster than a deep stack of grain. As air will take the path of least resistance, make sure the grain is spread out to an even depth.

16 GRDC Stored Grain Information Hub: Dealing with high moisture grain, http://storedgrain.com.au/dealing-with-high-moisture-grain/

Ducting for drying

The way to avoid hot spots is with adequate ducting to deliver an evenly distributed flow of air through the entire grain stack (Photo 10). A flat-bottom silo with a full floor aeration plenum is ideal providing it can deliver at least 15 l/s/t of airflow. The silo may only be able to be part filled, which in many cases is better than trying to dry grain in a cone-bottom silo with insufficient ducting.

Photo 10: *Aeration drying requires careful management, high airflow rates, well designed ducting, exhaust vents and warm, dry weather conditions.*

Source: GRDC

Venting for drying

Adequate ventilation maximises airflow and allows moisture to escape rather than forming condensation on the underside of the roof and wetting the grain on the top of the stack. The amount of moisture that has to escape with the exhaust air is 10 L for every one per cent moisture content removed per tonne of grain.

Weather conditions for drying

For moisture transfer to occur and drying to happen, air with a lower relative humidity than the grain's equilibrium moisture content must be used. In order to dry this wheat from its current state, the aeration drying fans would need to be turned on when the ambient air was below 70% relative humidity.

Phase one of drying

Aeration drying fans can be turned on as soon as the aeration ducting is covered with grain and left running continuously until the air coming out of the top of the storage has a clean fresh smell. The only time drying fans are to be turned off during this initial, continuous phase is if ambient air exceeds 85% relative humidity for more than a few hours.

Phase two of drying

By monitoring the temperature and moisture content of the grain in storage and referring to an equilibrium moisture table, such as Table 6, a suitable relative humidity trigger point can be set. As the grain is dried down the equilibrium point will also fall, so the relative humidity trigger point will need to be reduced to dry down the grain further. Reducing the relative humidity trigger point slowly during phase two of the drying process will help keep the difference in grain moisture from the bottom to the top of the stack to a minimum, by ensuring the fans get adequate run time to push each drying front right through the grain stack.

Table 6: *Equilibrium moisture content for wheat.*

Relative humidity (%)	Temperature 15	25	35	
30	9.8	9.0	8.5	Grain moisture content %)
40	11.0	10.3	9.7	
50	12.1	11.4	10.7	
60	13.4	12.8	12.0	
70	15.0	14.0	13.5	

Source: GRDC

Supplementary heating

Heat can be added to aeration drying in proportion to the airflow rate. Higher airflow rates allow more heat to be added as it will push each drying front through the storage quick enough to avoid over heating the grain close to the aeration ducting. As a general guide, inlet air shouldn't exceed 35°C to avoid over heating grain closest to the aeration ducting.

Cooling after drying

Regardless of whether supplementary heat is added to the aeration drying process or not, the grain should be cooled immediately after it has been dried to the desired level. [17]

13.3.4 Aeration controllers

Aeration controllers manage both aeration drying, cooling and maintenance functions in up to ten separate storages (Photo 11). The unit takes into account the moisture content and temperature of grain at loading and the desired grain condition after time in storage, and selects air accordingly to achieve safe storage levels.

A single controller has had the ability to control the diverse functions of aeration: cooling, drying and maintenance. The controller can not only control all three functions, but also automatically selects the correct type of aeration strategy to obtain the desired grain moisture and temperature. [18]

Research has shown that with the support of an aeration controller, aeration can rapidly reduce stored grain temperatures to a level that helps maintain grain quality and inhibits insect development.

During trials where grain was harvested at 30°C and 15.5% moisture, grain temperatures rose to 40°C within hours of being put into storage.

An aeration controller was used to rapidly cool grain to 20°C and then hold the grain between 17–24°C from November through to March.

Before replicating similar results on-farm, growers need to:

MORE INFORMATION

Dealing with high moisture grain

VIDEOS

WATCH: Aeration drying—getting it right

17 GRDC Stored Grain Information Hub: Dealing with high moisture grain, http://storedgrain.com.au/dealing-with-high-moisture-grain/

18 GRDC (2007) Ground Cover Issue 57—New Generation in aeration controller, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-57-Grain-Storage-Supplement/New-generation-aeration-controller

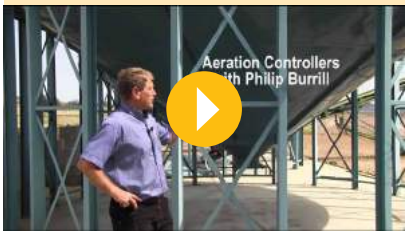
- Know the capacity of their existing aeration system.
- Determine whether grain requires drying before cooling can be carried out.
- Understand the effects of relative humidity and temperature when aerating stored grain.
- Determine the target conditions for the stored grain.

Photo 11: *Automatic aeration controllers are the most effective way to cool grain and are designed to manage many storages, from one central control unit.*

Source: GRDC

VIDEOS

WATCH: Aeration controllers with Philip Burrill



13.4 Grain protectants for storage

Lesser grain borer's (*Rhyzopertha dominica)* widespread resistance to grain protectants is coming to an end with the availability of deltamethrin (e.g. K-Obiol) and spinosad (e.g. Conserve On-Farm) products.

K-Obiol Combi

K-Obiol is a synergised grain protectant for use on cereal grains, malting barley and sorghum. It can be used in any type of storage, sealed or unsealed. It is suitable for use by grain growers and grain accumulators. Like all protectants it is a liquid, and must be evenly applied as a dilution to the grain as it is fed into the storage. It is not suitable for oil seeds or pulses. It is for use on un-infested grain and is not recommended for eradicating insect pests when they have infested grain.

The active constituent is deltamethrin. Piperonyl butoxide is added as a synergist; meaning it increases the effectiveness of the deltamethrin. As K-Obiol is based on deltamethrin there are none of the insect resistance problems being experienced with other protectants.

Because protectants are residual, there can be concern by grain users that the grain does not contain excessive levels. This may come about from incorrect treatment or double treatment as the grain moves along the supply chain. To protect the end user of the grain, and ultimately the Australian grain growers, a Product Stewardship program has been developed to ensure correct use of the product. The program will also ensure the product is used in a way that minimises the development of insect resistance and increases its usable life. [19]

19 GRDC Stored Grain information hub. K-Obiol Combi, http://storedgrain.com.au/k-obiol-combi/

Conserve On-farm

Conserve On-Farm is a grain protectant from DOW that has three active ingredients to control most major insect pests of stored grain, including the resistant lesser grain borer (LGB).

Conserve On-Farm provides six to nine months of control and has a nil withholding period (WHP).
Maximum residue limits (MRLs) have been established with key trading partners and there are no meat residue bioaccumulation issues.

Conserve On-Farm is a combination of two parts that are applied together.
Using Part A and Part B together is very important to get control of the complete spectrum of insects.

Part A: 1 x 5 L of chlorpyrifos-methyl and S-methoprene: controls all stored grain insect pests other than the resistant lesser grain borer (Rhyzopertha dominica)

Part B: 2 x 1 L of spinosad: is very effective on the lesser grain borer, including resistant strains, but has little to no activity on other key species. [20]

20 GRDC Stored Grain information hub. Conserve On-farm, http://storedgrain.com.au/conserve-farm/

Environmental issues

Key messages

- Durum is thought to be more susceptible to frost than bread wheat. [1]
- There has been an increase in frost frequency in many areas in the last 20 years.
- Waterlogging is one of the limiting factors influencing durum wheat production. [2]
- Heat stress can reduce durum yield. [3]
- High saline and sodic soils can negatively influence durum growth. [4]
- Both very hot and very cold temperatures around flowering can be particularly damaging to durum.

14.1 Frost issues for durum

Key points

- Frost is estimated to cost south-east Australia at least $100 million a year in unfulfilled or lost yield potential. [5]
- The relative resistance to freezing of cereals is (from most resistant): Rye > Bread wheat > Triticale > Barley > Oats and Durum wheat. [6]
- Cereal crops are most susceptible to frost injury during and after flowering, and may also be susceptible at booting. Losses in grain yield and quality from frost primarily occurs between stem elongation and late grainfilling. [7]
- Frost events can have major and sudden impacts on cereal yields (Photo 1).
- Frost is a relatively rare occurrence but some areas are more prone to it.
- Minor agronomic tweaks might be necessary in some frost prone areas
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect all the damage. [8]

1 Tony Craddock. (2016). Personal Communication.

2 Pampana, S., Masoni, A., & Arduini, I. (2016). Grain yield of durum wheat as affected by waterlogging at tillering. *Cereal Research Communications*, *44*(4), 706-716.

3 Modhej, A., Naderi, A., Emam, Y., Aynehband, A., & Normohamadi, G. (2012). Effects of post-anthesis heat stress and nitrogen levels on grain yield in wheat (T. durum and T. aestivum) genotypes. *International Journal of Plant Production*, *2*(3), 257-268.

4 Rajper, I., Wright, D., & Sial, N. B. (2003). Effect of soil salinity and sodicity on the growth and yield of durum wheat (Triticum turgidum L.) genotypes. *Pakistan Journal of Agriculture: Agricultural Engineering Veterinary Sciences (Pakistan).*

5 R Barr (2016) Diversity the key to balancing frost-heat risks, https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks

6 FAO. Chapter 4 – Frost damage: Physiological and critical temperatures. http://www.fao.org/docrep/008/y7223e/y7223e0a.htm

7 M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian grains. Grains Research and Development Corporation and South Australian Research and Development Institute, June 2007, https://grdc.com.au/Resources/Bookshop/2007/06/Managing-Frost-Risk-a-guide-for-southern-Australian-grains

8 D Grey (2014) GRDC Update Papers: Frost damage in crops—where to from here? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

Photo 1: *Frost damaged wheat.*

Source: Rachel Bowman

MORE INFORMATION

Frost and plant physiology: Q&A with Glenn Macdonald

VIDEOS

WATCH: Plant frost mechanisms—explained

Crop losses due to frost are estimated to average more than $33 million a year in South Australia (SA) and Victoria. Spring radiant frost damage to cereals post head emergence causes significant yield losses in Australia. Frost in cereals can be more devastating than drought as it has a sudden impact. Typically during the winter-spring growing season, day time temperatures are ideal for growth but night time temperatures can fall to potentially damaging levels. Wheat can be affected when the canopy air temperature reaches -1°C at flowering, with damage increasing as the temperature falls further. On nights when still, cold air, clear skies and low humidity combine, temperatures drop rapidly, resulting in radiant frost. Freezing of crops is a physical process moderated by factors such as plant development stage and temperature. The crop canopy temperatures experienced and recorded can vary widely due to differences in topography, micro-environment and recording method. [9]

Table 1 outlines the atmospheric conditions on the afternoon and evening prior to a frost event.

Table 1: *Atmospheric conditions leading up to a frost event.*

Measurement	3 pm–6 pm	6 pm–9 pm	Frost
Temperature at screen height	16 → 18°C	12 → 6°C	<2°C
Cloud cover	Very low	Low	Nil
Wind speed	<3 m/s	<1 m/s	0 m/s
Barometric pressure	1008–1009	1008–1009	1004–1008

Source: Primary Industries and Regions South Australia

9 T Frederiks, C Birchall, J Christopher, A Borrell (2011) Frost resistance in cereals after head-emergence. GRDC update papers. Grains Research and Development Corporation, April 2011,

14.1.1 Varietal susceptibility

Durum is more susceptible to frost damage than bread wheat (Figure 1).

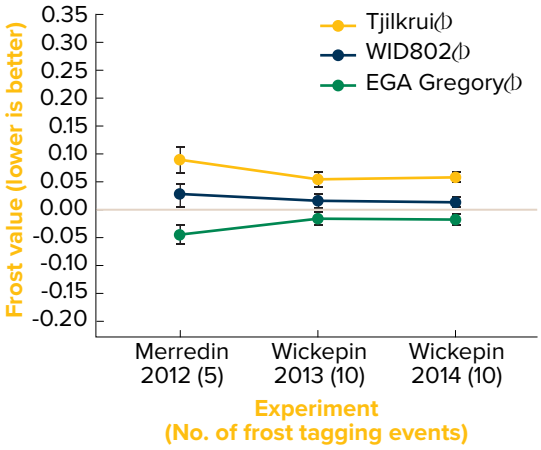


Figure 1: *Frost Value performances of two durum lines and one bread wheat line as part of experiments in the National Frost Initiative. Note that the dashed line presents an average variety for that trial and that lower values are better for frost tolerance.*

Source: NVT online, National Frost Initiative.

Recent 'time of sowing' trials in New South Wales saw a decrease in durum yield due to a -3.3°C frost event, which induced sterility. This event coincided with full head emergence and/or early anthesis for DBA Lillaroi (GS59 – GS61). Both Caparoi (~GS53 - GS55) and DBA Aurora (~GS55 - GS57) which were less advanced during this frost event also experienced yield losses of ~ 18% (1.00t/ha) and ~26% (1.37t/ha) respectively when sown on April 23. Results from this experiment indicate that DBA Lillaroi appears able to maintain grain stability (plumpness-reduced screenings) over a wide sowing window, with improved grain size relative to Caparoi. DBA Lillaroi, however, was more exposed to frost risk on the earlier sowing time, reinforcing the need to match maturity type to sowing time. Sowing date and variety selection is considered a balancing act between frost risk and early onset moisture/evaporative stress. [10]

High frost risk areas in southern Australia include the Eyre Peninsula, Murray-Mallee, the Mid-North of SA and the Wimmera-Mallee region of Victoria. Crop production losses can be close to 100% in the worst affected areas. Despite an increase in annual maximum temperatures since 1960, there has not been a corresponding decrease in the number of frost events throughout southern Australia. This is probably due to the atmospheric conditions leading up to a frost having a significant impact on minimum temperatures, particularly the lack of cloud cover and no wind. In below average rainfall seasons there is often an increase in the incidence and severity of frost, due to reduced cloud cover and lower soil moisture reducing the humidity of the air mass in the crop canopy. [11]

Clear, calm and dry nights following cold days are the precursor conditions for radiation frost (or hoar frost). These conditions are most often met during winter and spring where high pressures follow a cold front, bringing cold air from the Southern Ocean but settled, cloudless weather (Figure 2). When the loss of heat from the earth during the night decreases the temperature at ground level to zero, a frost

10 Graham R, McMullen G, Simpfendorfer S, Morphett S and Graham N. (2016). GRDC Update Papers: Durum agronomy a northern perspective. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Durum-agronomy-a-northern-perspective

11 PIRSA (2003). Impact of dry sow, frost, crop type and variety. http://pir.sa.gov.au/__data/assets/word_doc/0005/241583/Impact_of_dry_sow,_frost,_crop_type_and_variety.doc

occurs. 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 its stays below zero and the how far below zero it gets.

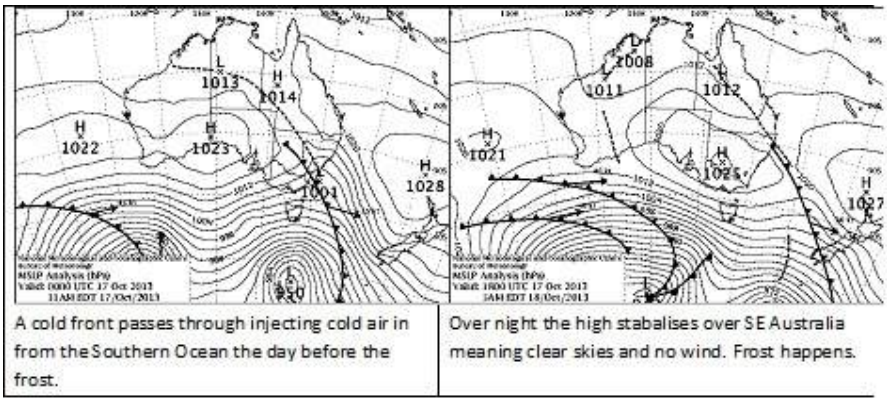


Figure 2: *A cold front passes through injecting cold air from the Southern Ocean the day before frost (left). Overnight the high pressure system stabilises over SE Australia meaning clear skies and no wind leading to a frost event (right).*

Source: GRDC

Though temperatures (particularly those in winter and spring) are getting warmer, frost is still a major issue. CSIRO researchers have found that there are areas of Australia where the number of frost events are increasing (greatest in August) with Central West New South Wales, Eyre Peninsula, Esperance and Northern Victoria (Mallee) the only major crop growing areas to be less affected by frost in the period 1961–2010 (Figure 3). This increase is thought to be caused by the latitude of the Sub Tropical Ridge of high pressure drifting south (causing more stable pressure systems) and more El Niño conditions during this period. [12]

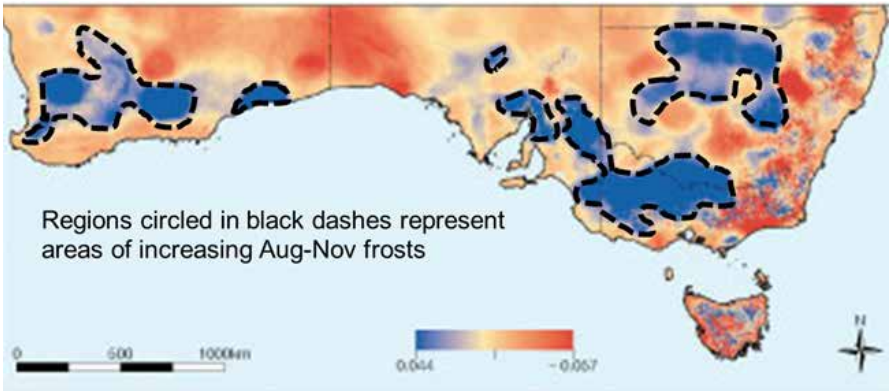


Figure 3: *Region of increasing August-November frost events.*

Source: Steven Crimp in GRDC

14.1.2 New insight in frost events and management

Take home messages

- Growers need to consider carefully whether earlier sowing is justified in seasons where warmer temperatures are predicted.
- Warmer temperatures may reduce the frequency of frost events but also increase the rate of crop development, bringing crops to the susceptible, post-heading stages earlier.

VIDEOS

WATCH: GCTV20: Frost's emotional impact, is it greater than its economic impact?

12 D Grey (2014) GRDC Update Papers: Frost damage in crops—where to from here? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

- Situation analysis of national frost impact indicates substantial losses in all regions averaging approximately 10% using current best practice.
- There can be even greater losses in yield potential due to late sowing.
- These results indicate that continued research into reducing frost risk remains a high priority despite increasing temperatures.
- Variety guides and decision support software are useful for matching cultivars to sowing opportunities.
- Current variety ratings based on floret damage may not provide a useful guide to head and stem frost damage.
- Crops become most susceptible to frost once awns emerge.
- If crop temperature at canopy height drops below -3.5C after awn emergence, crops should be assessed for damage.
- Consider multiple sowing dates and or crops of different phenology to spread risk.

The first nationwide assessment of the comparative impact of frost in different Australian cropping regions provides important insights into how to manage frost risk in Australian cropping environments.

Climate data from 1957–2013 has been used to assess the frequency and severity of frost for each region of the Australian cropping belt. Night time minimum temperatures have been observed to increase over much of the Australian cropping region during that period. However, analysis showed that frost risk and frost impact did not reduce over the whole cropping area during that time. Warmer temperatures accelerate plant development causing crops to develop to the frost-susceptible, heading stages more rapidly. So, counter intuitively, planting earlier or even at the conventional date during warmer seasons may sometimes increase frost risk.

Historic climate data from a grid database and for 60 locations representing each of the four major cropping regions of Australia was used to determine the frequency and severity of frost (Figure 4, top). Crop simulation modelling using the Agricultural Production Systems sIMulator program (APSIM) was used to estimate crop yields. Expert knowledge combined with data from frost trials was used to estimate crop losses. Computer simulation allowed prediction of crop losses for all Australian cropping regions using damage information from a limited number of frost trial sites. It also allowed simulation of potential yields using sowing dates optimised for yield in the hypothetical absence of frost risk, something that has not been achieved experimentally.

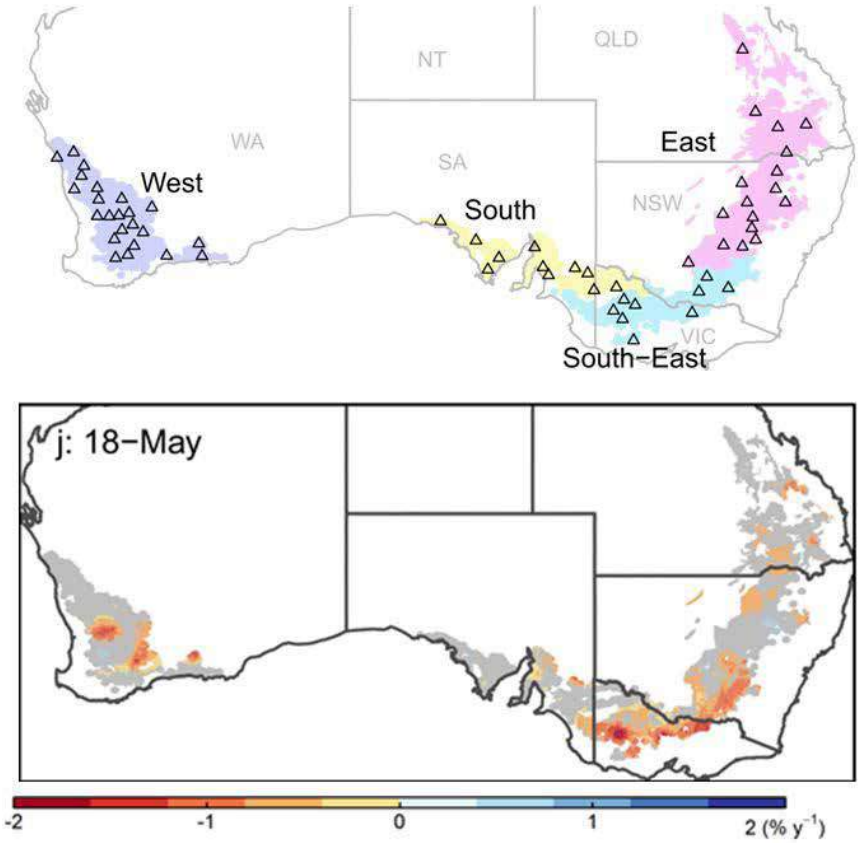


Figure 4: *Maps showing sites and regions for which climate data were analysed for the frequency and severity of frosts (top panel) and annual % change in yield loss due to frost from 1957 to 2013; negative values (yellow to red) represent areas where yield loss became worse over recent decades (bottom panel). Estimations in the lower panel were for the cultivar Janz sown 18 May and are based on a ~ 5 x 5 km grid of climatic data. (Gridded climate data may not reflect local climatic conditions of particular paddocks within each grid as frost events are highly spatially variable.).*

Source: GRDC

The study revealed that estimated yield losses due to direct frost damage averaged close to 10% nationally for all crop maturity types, following current sowing guidelines (Figure 5). To estimate the loss of yield potential due to late sowing, which is necessary in many areas to manage frost risk, a theoretical optimal sowing date (as early as 1 May) was used. When lost yield potential from delayed sowing (indirect cost of frost) is added to direct damage, estimated yield losses approximately double from 10% to 20% nationally ("direct + indirect" impact in Figure 5). In the eastern grains region (Queensland to central NSW) losses were even greater, with estimated yield losses due to direct damage and delayed sowing (indirect losses) of 34%, 38% and 23% for early, mid and late flowering cultivars, respectively (Figure 5).

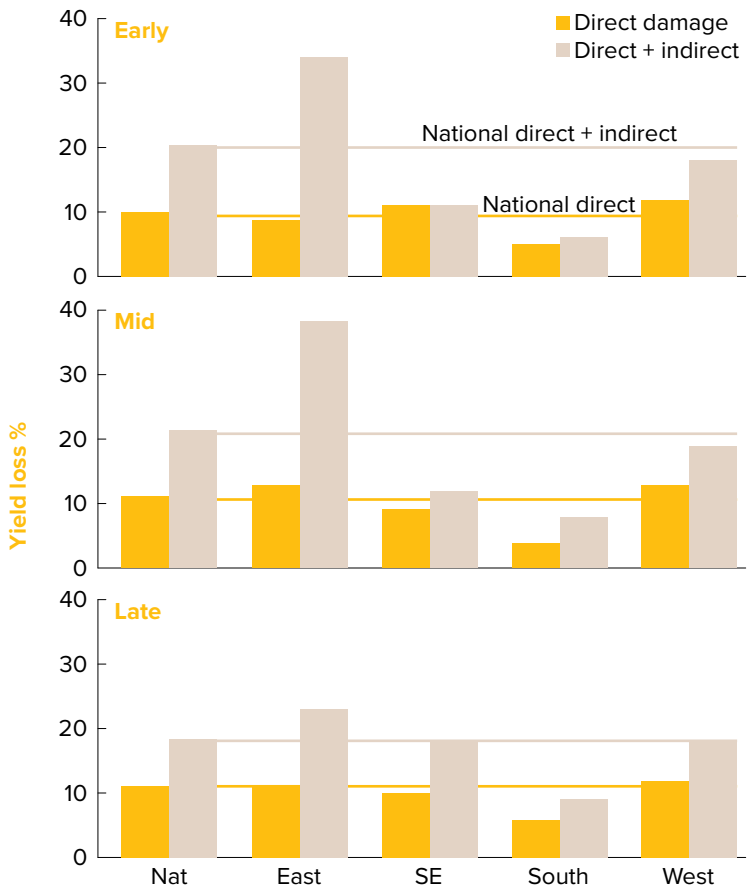


Figure 5: *Estimated wheat yield losses (%) due to frost damage for crops sown at the current best sowing date ("direct" frost damage); and crop losses due to both direct damage and delayed sowing currently necessitated to manage frost risks (direct + indirect) for early, mid and late flowering crops.*

Source: GRDC

In some areas in each region, simulated frost impact has significantly increased between 1957 and 2013 (yellow, orange and tan areas, Figure 4, bottom panel). Estimated date of last frost has come later in some areas but earlier in others. However, even in areas where the date of the last frost has come significantly earlier, increased temperatures have also increased the rate of development to frost-susceptible heading stages. The modelling suggests that crop heading dates have been brought forward more rapidly than the date of last frost, leading to an overall modelled increase in frost impact in many areas.

These trends over time may have implications for growers making planting decisions. They indicate that sowing early to increase yield potential may not always be the best course of action in warmer seasons, even when a lower frequency of frost events is anticipated. By increasing the rate of crop development, warmer temperatures cause the crop to develop more rapidly to the frost susceptible, heading stages, which may actually increase frost risk.

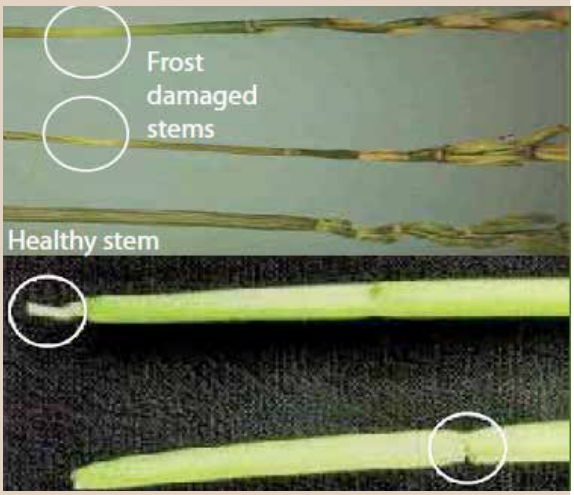
These results indicate that continued research to reduce frost risk remains a high priority despite increasing temperatures due to climate change. Counter intuitively, percentage yield losses are greatest in the Northern Grain region, with the greatest yield losses actually due to delayed sowing rather than frost.

Results from this Frost Situation Analysis will provide valuable insights allowing GRDC to better direct research resources. They also provide valuable insights for managing frost risk now.

14.1.3 Diagnosing stem and head frost damage in cereals

Table 2: *Symptoms of frost during early growth stages.*

Crop growth stage	Inspection Details	Frost symptoms in wheat	Example
Vegetative (before stem extension)	Examine leaves.	Leaves are limp and appear brown and scorched.	

Crop growth stage	Inspection Details	Frost symptoms in wheat	Example
Elongation (before and after head emergence)	Pull back leaf sheath or split stem to inspect damage.	The stem has a pale green to white ring that usually appears sunken, rough to touch and soft to squeeze. The stem or nodes can also be cracked or blistered. Stems can be damaged on the peduncle (stem below head) or lower in the plant. If the head had emerged at the time of the frost then it is likely that the flowering parts or developing grain has also sustained damage. If the head is in the boot then ongoing monitoring is required to assess the level of damage.	 
Flowering and post-flowering	Peel back the lemma (husk), inspect the condition of the florets (floral organs) in the head.	Flowering is the most vulnerable stage, because exposed florets cannot tolerate low temperatures and are sterilised. Grain will not form in frosted florets, but some surviving florets may not be affected. Pollen sacs (anthers) are normally bright yellow but become dry, banana-shaped and turn pale yellow or white.	

Source: GRDC

What to look for

Paddock

- Symptoms may not be obvious until five to seven days after the frost.
- Heads on affected areas have a dull appearance that becomes paler as frosted tissue dies (Photo 2).
- At crop maturity severely frosted areas remain green longer.
- Severely frosted crops crop have a dirty appearance at harvest due to blackened heads and stems, and discoloured leaves.

Photo 2: *Frost damage in wheat at Black Rock in the South Australian Upper North.*

Photo Jim Kuerschner. Source: GRDC

Plant

Before flowering:

- Freezing of the emerging head by cold air or water is caught next to the flag leaf or travelling down the awns into the boot. Individual florets or the whole head can be bleached and shriveled, stopping grain formation. Surviving florets will form normally.
- Stem frost results a small amount of water that has settled in the boot and frozen around the peduncle. Symptoms include paleness or discolouration and roughness at the affected point on the peduncle, and blistering or cracking of nodes and leaf sheath. Stems may be distorted.

Flowering head:

- The ovary in frosted flowers is “spongy” when squeezed and turns dark in colour.
- Anthers are dull coloured and are often banana shaped. In normal flowers the ovary is bright white and “crisp” when squeezed. As the grain develops it turns green in colour. Anthers are green to yellow before flowering or yellow turning white after flowering

Grain:

- Frosted grain at the milk stage is white, turning brown, with a crimped appearance. It is usually spongy when squeezed and doesn't exude milk/dough. Healthy grain is light to dark green and plump, and exudes white milk/dough when squeezed (Photo 3).

- Frosted grain at the dough stage is shrivelled and creased along the long axis, rather like a pair of pliers has crimped the grain (Photo 4). [13]

Photo 3: *A normal cereal head (left) compared to frost damaged cereal showing discoloured glumes and awns.*

Source: DAFWA

Photo 4: *Frosted hollow grain dries back to the typical shrivelled frosted grain.*

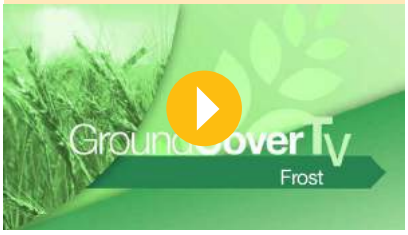
Source: GRDC

VIDEOS

WATCH: GCTV15: Frost Ratings.

WATCH: GCTV15: The frost ranking challenge.

WATCH: GCTV12: Frost susceptibility ranked.



13 DAFWA (2015) Diagnosing stem and head frost damage in cereals. https://www.agric.wa.gov.au/mycrop/diagnosing-stem-and-head-frost-damage-cereals

14.1.4 Resistance or tolerance to frost

Frost events in spring cause major economic losses to the wheat industry across Australia through direct yield losses, quality downgrading and indirect losses through delayed seeding to reduce to reduce frost risk. To date, management practices available to growers are largely limited to diversifying flowering dates and minimising inputs in particularly frost prone paddocks.

Growers can lower frost risk in paddocks that frequently experience frost by growing either more frost-tolerant crops or growing pastures. [14]

Historically, breeding for frost tolerance has been constrained because a robust and reliable method for accurately measuring frost damage has not been available to breeders. Over the past decade researchers have developed and refined field-based screening methods to reliably measure frost tolerance in barley. These methods have been used successfully to identify barley lines with superior frost tolerance. We are now in a position to apply this knowledge and methods to improve frost tolerance in Australian wheat varieties.

The GRDC project UA00114 is investigating frost tolerance in southern Australia. Initially the frost tolerance observed within two particular synthetic derived lines will be confirmed, particularly in the context of conventional seeding dates. This will be followed by genetic analysis within populations specifically developed for investigating frost tolerance. A smaller component of the project will examine specific lines developed from the incorporation of the winter hardiness genes from the Canadian variety 'Norstar' into Australian germplasm with spring growth habit for frost tolerance at flowering. Successful achievement of these aims is expected to result in adoption of the germplasm and associated molecular markers by breeding organisations to support the development of wheat varieties with improved frost tolerance. Frost screening will utlilise the successful approaches employed in barley projects and the previous GRDC wheat project UA00073. Field screening will be based at Loxton in the South Australian Mallee which reliably experiences significant frost events in late winter and spring. Up to nine seeding dates will be used to maximise the probability of test lines flowering when a frost event occurs. [15]

MORE INFORMATION

NVT Frost Rankings

14.1.5 Managing frost risk

Key points

- In some areas the risk of frost has increased due to widening of the frost event window and changes in grower practices.
- The risk, incidence and severity of frost varies between and within years as well as across landscapes, so growers need to assess their individual situation regularly.
- Frosts generally occur when nights are clear and calm and follow cold days. These conditions occur most often during winter and spring.
- 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.
- 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.
- Methods to deal with the financial and personal impact of frost also need to be considered in a farm management plan.

14 DAFWA (2016) Frost and cropping. Department of Agriculture and Food Western Australia, August 2016, https://www.agric.wa.gov.au/frost/frost-and-cropping

15 GRDC (2013) UA00114: Frost tolerance in wheat. Grains Research and Development Corporation, http://projects.grdc.com.au/projects.php?action=view_project&project_id=1904

- Careful planning, zoning and choosing the right crops are the best options to reduce frost risk. [16]

To assist with early assessment of frost damage, accurate maximum–minimum field thermometers measuring temperatures at crop head height are useful. Minimum air temperatures measured at crop head height can be several degrees colder than temperatures measured in the Stevenson screen, as reported by the Bureau of Meteorology. For best results, at least two or three field thermometers are required to give representative temperatures throughout a crop. In undulating country, more thermometers should be used at various heights in the landscape. [17]

Table 3 outlines a number of agronomic practices to reduce frost risk.

Table 3: *Agronomic practices to reduce frost risk, ranked in order of importance.*

Soil heat bank manipulation	Average increase in temperature at canopy height	Reduction in frost damage
Clay delving or clay spreading on sandy surfaced soils	1°C	Up to 80%
Rolling sandy and loamy clay soil after seeding	0.5°C	Up to 18%
Removing stubble (this had a negligible effect on yield and frost risk; in 2014 cereal stubbles increased frost risk on dark soils)	0.5°C	Minimal
Manipulation of the crop canopy		
Blending long and short season wheat varieties of the same quality classification	0°C	Later maturing variety: 12%
Sowing later maturing varieties towards the middle or end of a sowing program		
Cross sowing with half the seed sown in each direction, to give a more even plant density so that soil heat is released more slowly	0.6°C	13%
Increasing row spacing and lowering seeding rates	0°C	0
Frost minimising strategies		
Applying adequate seed and fertiliser inputs for target yield, rather than high inputs.		
Delaying sowing on frost prone paddocks can reduce frost risk, however it also increases the risk of end of season drought.		
Growing lower risk crops such as oats (approx. 4°C more tolerant) and long season barley (approx. 2°C more tolerant) can reduce losses from frost compared to wheat.		
Frost avoidance strategy		
Growing hay or permanent pasture on highly frost prone areas.		

Source: Primary Industries and Regions South Australia

16 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

17 T Frederiks, C Birchall, J Christopher, A Borrell (2011) Frost resistance in cereals after head-emergence. GRDC update papers. Grains Research and Development Corporation, April 2011,

Guidelines for reducing frost risk and assessing frost damage

Matching variety to planting opportunity

The current best strategy to maximise long term crop yields is to aim to time crop heading, flowering and grain filling in the short window of opportunity after the main frost risk period has passed and before daytime maximum temperatures become too high.

It is essential that varieties are sown within the correct window for the district as outlined in variety guides.

Planting in the optimum window does NOT guarantee that crop loss due to frost will be averted, nor does it always prevent drastic yield reduction due to late season heat and drought stress. However, planting a variety too early can lead to a very high probability of crop loss.

With seasonal temperature variation the days to flowering for each variety will change from season to season, as discussed above.

Current variety ratings based on floret damage may not provide a useful guide. Floret damage ratings are yet to be correlated with more significant head and stem damaging frosts.

Measuring crop temperature

In-crop temperature measurements are useful to determine whether a crop may have been exposed to damaging temperatures. A historic comparison of on-farm and district minimum temperatures also allows growers to fine-tune district management recommendations to better suit their particular property and individual paddocks. District recommendations are based on one, or at best a few sites, for each district and may not correlate well with the experience of individual growers. Thus in many instances, the recommendations likely err on the side of caution.

Stevenson screen temperatures measured at Bureau of Meteorology stations do not fully explain frost risk. In crops, the temperature can vary several degrees from the temperature measured in the screen. On nights when still cold air, clear skies, and low humidity conditions combine, temperatures can drop rapidly, resulting in radiant frost (Figure 6). The crop temperatures experienced and recorded can vary widely due to differences in topography, micro-environment and recording method.

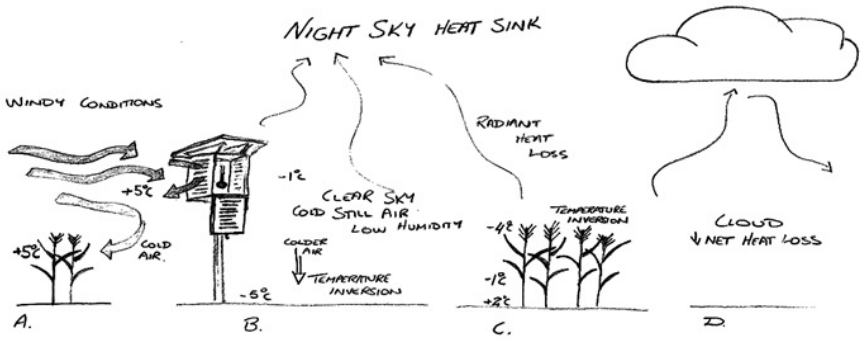


Figure 6: *If clear skies and still, cold, low humidity air coincide, heat can be lost rapidly to the night sky resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than reported "screen" temperatures. Some indicative temperatures are illustrated for (A) windy conditions, (B) clear still conditions in an open area, (C) clear still conditions in a cropping area, and (D) cloudy conditions.*

Measurements taken using exposed thermometers at canopy height (Photo 5) give a much more accurate indication of the likelihood of crop damage. [18]

Photo 5: *Canopy temperature measured using a calibrated minimum/maximum thermometer. For best results, a minimum of two or three field thermometers are require to give representative temperatures for a crop. In undulating country, more thermometers should be used to record temperatures at various heights in the landscape.*

Source: GRDC

14.1.6 Sowing dates to avoid frost

To lower the risk of frost damage, winter cereals are planted 'late' so that heading and grain development occur when warmer temperatures prevail. Unfortunately, this delay increases the likelihood of drought and high temperatures during anthesis and grainfilling, dramatically reducing yield potential. Yield declines of as much as 16% for each week that flowering is delayed past the optimum time have been reported. Optimum flowering time and yields are achieved, in the long term, when a compromise between the effects of frost and drought is reached. [19]

Durum wheats are generally similar in maturity to the quickest bread wheat varieties. This is an important consideration when managing frost risk and can limit opportunities to exploit early planting opportunities. Extended flowering could reduce the risk of pollination failure caused by frost or extended moist weather.

Delaying sowing after the optimum sowing date is not economical in the long term, even in high frost risk areas. The yield loss from moisture and temperature stress during spring will be far greater than the damage caused by frost. The most severe and damaging frosts are those associated with dry conditions in mid to late spring (black frosts), which can be devastating even to crops that have completed flowering. Crops sown at the optimum time will generally be less affected by these late frosts, as they will be past the critical flowering stage. [20]

Table 5 is a simple spreadsheet model calculating the chance of minimum temperature for each sowing date, using long term records (in this case, sourced from the Bureau of Meteorology site at Keith, SA). The calculated long term yield loss

18 J Christopher, G Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) GRDC Update Papers: An analysis of frost impact plus guidelines to reduce frost risk and assess frost damage, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/An-analysis-of-frost-impact-plus-guidelines-to-reduce-frost-risk-and-assess-frost-damage

19 T Frederiks, C Birchall, J Christopher, A Borrell (2011) Frost resistance in cereals after head-emergence. GRDC update papers. Grains Research and Development Corporation, April 2011,

20 PIRSA (2003). Impact of dry sow, frost, crop type and variety. http://pir.sa.gov.au/__data/assets/word_doc/0005/241583/Impact_of_dry_sow,_frost,_crop_type_and_variety.doc

is simply the chance of a frost event occurring multiplied by the damage estimate from that event. For example, the first column 61.2% x 0% loss + 18.4% x 10% loss + 14.3% x 20% loss + 4.1% x 25% loss + 2% x 80% loss equates to a long term average loss of 7.6%. [21]

Table 4: *Investigating the effect of sowing date on frost risk and wheat yields for Keith, SA.*

Sowing date	15 May	1 June	15 June	30 June
Yield penalty	0%	12%	22%	33%
Yield (t/ha)	2.7	2.4	2.1	1.8
Days to flower	117	114	111	106
Flowering date	9 Sept	23 Sept	4 Oct	14 Oct
Chance of minimum temperature (meteorological station) and estimated damage in the field				
>2°C (assume no loss)	61.2%	61.2%	73.5%	73.5%
2 to 1°C (assume 10% loss)	18.4%	20.4%	10.2%	14.3%
1 to 0°C (assume 20% loss)	14.3%	12.2%	10.2%	8.2%
0 to -1°C (assume 25% loss)	4.1%	4.1%	4.1%	2.0%
-1 to -2°C (assume 80% loss)	2.0%	2.0%	2.0%	2.0%
-2 to -3°C (assume 90% loss)	0.0%	0.0%	0.0%	0.0%
-3 to -4°C (assume 100% loss)	0.0%	0.0%	0.0%	0.0%
Calculated long term average yield loss from frost	7.3%	7.1%	5.7%	5.2%

Source: Grains Research and Development Corporation and South Australian Research and Development Institute

For more information see Section 2: Pre-planting and Section 3: Planting.

14.1.7 What to do with a frosted crop

Once a frost event (especially at or after flowering) has occurred, the first step is to inspect the affected crop and collect a (random) sample of heads to estimate the yield loss incurred.

In the event of severe frost (Photo 6) monitoring needs to occur for up to two weeks after the event to detect all the damage. After the level of frost damage is estimated, the next step is to consider options for the frost damaged crop.

21 M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian grains. Grains Research and Development Corporation and South Australian Research and Development Institute, June 2007, https://grdc.com.au/Resources/Bookshop/2007/06/Managing-Frost-Risk-a-guide-for-southern-Australian-grains

Photo 6: *Severely frosted areas mature later and are often stained/discoloured.*

Source: DAFWA

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. Tillers already formed but lower in the canopy may become important and new tillers can grow after frost damage, depending on the location and severity of the damage. These compensatory tillers will have delayed maturity, but where soil moisture reserves are high, or it is early in the season, they may be able to contribute to grain yield.

A later frost is more concerning, especially for crops such as wheat and barley, as there is less 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 area than originally intended pre-season. Producing 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. In high frost risk areas, durum growers may consider planting a variety like Saintly which has small awns and more suitable for hay should frosted crop need to be cut for hay.

Option 3: Grazing, manuring and crop topping

Grazing is an option after a late frost, when there is little or no chance of plants recovering, or when hay is not an option. Spraytopping for weed seed control may also be incorporated, especially if the paddock will be sown to crop the next year. Ploughing in the green crop is to return organic matter and nutrients to the soil, manage crop residues, weeds and improve soil fertility and structure. The economics need to be considered carefully. [22]

22 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

Table 5: *Management options for frost damaged crop, each with advantages and disadvantages.*

Options	Potential Advantages	Potential Disadvantages
Harvest	Salvage remaining grain More time for stubble to break down before sowing Machinery available	May be greater than return Need to control weeds Threshing problems Removal of organic matter
Hay / Silage	Stubble removed Additional weed control	Costs $35–$50/t to make hay Quality may be poor Nutrient removal
Chain / Rake	Retains some stubble (Reduces erosion risk) Allows better stubble handling	Costs $5/ha raking Time taken
Graze	Feed value	Inadequate stock to use feed Remaining grain may cause acidosis Stubble may be difficult to sow into
Spray	Stops weeds seeding Preserves feed quality for grazing Gives time for final decisions Retains feed Retains organic matter	Difficulty getting chemicals onto all of the weeds with a thick crop May not be as effective as burning Boom height limitation Expense $5/ha plus cost of herbicide Some grain still in crop
Plough (Cultivate)	Recycles nutrients and retains organic matter. Stop weed seed set Green manure effect	Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swath	Stops weed seed set Windrow can be baled Regrowth can be grazed Weed regrowth can be sprayed	Relocation of nutrients to windrow Low market value for straw Poor weed control under swath Expense—swathing ($20/ha) Spraying ($5/ha per herbicide)
Burn	Recycles some nutrients Controls surface weed seeds Permits re-cropping with disease control Can be done after rain	Potential soil and nutrient losses Fire hazard Organic matter loss

Source: GRDC

Useful tools

- Weather apps: see AgExcellence Alliance for a review.
- Plant development apps (e.g. MyCrop, DAFWA FlowerPower)
- Temperature monitors

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:

MORE INFORMATION

Managing frost risk—a guide for southern Australian growers.

Ranking cereals for frost susceptibility using frost values—southern region.

GRDC Managing frost risk Factsheet.

VIDEOS

WATCH: GCTV3: Frost R&D.

WATCH: GCTV16: National Frost Initiative.

1. Genetics: developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.
2. 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.
3. Environment: predicting the occurrence, severity and impact of frost events on crop yields and frost events at the farm scale to enable better risk management. [23]

14.2 Waterlogging/flooding issues for durum

Key points:

- Waterlogging occurs when roots cannot respire due to excess water in the soil profile.
- Water does not have to appear on the surface for waterlogging to be a potential problem.
- Improving drainage from the inundated paddock can decrease the period in which the crop roots are subjected to anaerobic conditions.
- While raised beds are the most intensive management strategy, they are also the most effective at improving drainage.
- Waterlogged soils release increased amounts of nitrous oxide, a particularly damaging greenhouse gas.

Waterlogging occurs when the soil profile or the root zone of a plant becomes saturated (Photo 7). In rain-fed situations, this happens when more rain falls than the soil can absorb or the atmosphere can evaporate. Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore space for plant roots to be able to adequately respire. Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and affect the plants.

Plants differ in their demand for oxygen. There is no universal level of soil oxygen that can identify waterlogged conditions for all plants. In addition, a plant's demand for oxygen in its root zone will vary with its stage of growth. [24]

Photo 7: *The 2016 July wet impacted producers in Murrumburrah.*

Source: Harden Express

23 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

24 D Bakker. Water-logging. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/waterlogging

Flooding and long periods of waterlogging can also cause the depletion of important nutrients (e.g. nitrogen) required for growth. Soil testing after flooding is recommended.

Waterlogging is one of the limiting factors influencing durum wheat production. One study investigated the impact of seven waterlogging durations of 4, 8, 12, 16, 20, 40, and 60 days (d), imposed at 3-leaf and 4-leaf growth stages, on grain yield, grain yield components, straw and root dry weight and nitrogen concentration of grain, straw, and roots of two varieties of durum wheat. Grain yield of both varieties showed a significant reduction only when waterlogging was prolonged to more than 20 days, and 40-d and 60-d waterlogging reduced grain yield by 19% and 30%. Waterlogging depressed grain yield preventing many culms from producing spikes. It slowed down spikelet formation, consequently reducing the number of spikelets per spike, and reduced floret formation per spikelet, thus reducing the number of kernels per spike. [25]

14.2.1 Effects on plant growth

Low levels of oxygen in the root zone trigger the adverse effects of waterlogging on plant growth. Waterlogging of the seedbed mostly affects germinating seeds and young seedlings. Established plants are most affected when they are growing rapidly. Therefore, if a soil becomes waterlogged in July, final yields may not be greatly reduced; soils are cold, the demand for oxygen is low and plant growth is slow at this time of year. Prolonged waterlogging during the warmer spring period could be more detrimental, however the probability of this occurring is much lower than in July.

When plants are growing actively, root tips begin to die within a few days of waterlogging. The shallow root systems that then develop limit the uptake of nutrients (particularly nitrogen) and water, particularly when the soil profile starts to dry in spring. As a result plants may ripen early and grains may not fill properly.

Nitrogen is lost from waterlogged soils by leaching and denitrification. Denitrification leads to the gaseous loss of nitrous oxide into the atmosphere, which is a major greenhouse gas. These losses, together with the lowered ability of plants to absorb nutrients from waterlogged soil, cause the older leaves to yellow. Waterlogging also directly reduces nitrogen fixation by the nodules of legume crops and pastures. [26]

Where does waterlogging occur?

- Water accumulating in poorly drained areas such as valleys, at the change of slope or below rocks.
- Duplex soils, particularly sandy duplexes with less than 30 cm sand over clay.
- Deeper sown crops.
- Waterlogging greatly increases crop damage from salinity. Germination and early growth can be much worse on marginally saline areas after waterlogging events.
- Low nitrogen status crops.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [27]

25 Pampana, S., Masoni, A., & Arduini, I. (2016). Grain yield of durum wheat as affected by waterlogging at tillering. *Cereal Research Communications*, *44*(4), 706-716.

26 D Bakker. Water-logging. Soil Quality Pty Ltd, http://soilquality.org.au/factsheets/waterlogging

27 DAFWA (2015) Diagnosing waterlogging in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

IN FOCUS

Crop production in the high rainfall zones of southern Australia—potential, constraints and opportunities

Annual cropping has been expanding in the high rainfall zone of southern Australia. The higher rainfall and longer growing season compared with the traditional wheat belt contribute to a much higher yield potential for major crops. Potential yields range from 5 to 8 t/ha for wheat and 3 to 5 t/ha for canola, although current crop yields are only about 50% of those potentials. The large yield gap between current and potential yields suggests that there is an opportunity to lift current yields. Both genetic constraints and subsoil constraints such as waterlogging, soil acidity, sodicity, and high soil strength contribute to the low yields. Waterlogging is a widespread hidden constraint to crop production in the region. Controlling waterlogging using a combination of raised beds and surface or subsurface drains is the first step to raise the productivity of the land. Increasing root growth into the subsoil remains a key to accessing more water and nutrients for high yield through early planting, deep ripping, liming and use of primer crops to ameliorate the subsoil. In order to realise the high yield potential, it is essential to achieve higher optimum dry matter at anthesis and high ear number through agronomic management, including early sowing with appropriate cultivars, a high seeding rate and application of adequate nitrogen along with other nutrients. Current cultivars of spring wheat may not fully utilise the available growing season and may have genetic limitations in sink capacity that constrain potential yield. Breeding or identification of long-season milling wheat cultivars that can fully utilise the longer growing season and with the ability to tolerate waterlogging and subsoil acidity, and with disease resistance, will give additional benefits. It is concluded that improving crop production in the high rainfall zone of southern Australia will require attention to overcoming soil constraints, particularly waterlogging, and the development of longer-season cultivars. [28]

Identifying problem areas

The best way to identify problem areas is to dig holes about 40 cm deep in winter and see if water flows into them (Photo 8). If it does, the soil is waterlogged. Digging holes for fence posts often reveals waterlogging. Some farmers put slotted PVC pipe into augered holes. They can then monitor the water levels in their paddocks.

Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- Presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [29]

28 H Zhang, NC Turner, ML Poole, N Simpson (2006) Crop production in the high rainfall zones of southern Australia—potential, constraints and opportunities. *Animal Production Science*, *46*(8), 1035-1049.

29 Soilquality.org. Waterlogging Factsheet, http://soilquality.org.au/factsheets/waterlogging

Photo 8: *Water fills a hole dug in waterlogged soil.*

Source: Soilquality.org

14.2.2 Symptoms and causes

Lack of oxygen in the root zone of plants causes their root tissues to decompose. Usually this occurs from the tips of roots, causing roots to appear as if they have been pruned. The consequence is that the plant's growth and development is stalled. If the anaerobic circumstances continue for a considerable time the plant eventually dies.

Most often, waterlogged conditions do not last long enough for the plant to die. Once a waterlogging event has passed, plants recommence respiring. As long as soil conditions are moist, the older roots close to the surface allow the plant to survive. However, further waterlogging-induced root pruning and/or dry conditions may weaken the plant to the extent that it will be very poorly productive and may eventually die.

Many farmers do not realise that a site is waterlogged until water appears on the soil surface. However, by this stage, plant roots may already be damaged and yield potential severely affected.

Waterlogging occurs when the soil profile or the root zone of a plant becomes saturated. In rain-fed situations, this happens when more rain falls than the soil can absorb or the atmosphere can evaporate.

What to look for

Paddock

- Poor germination or pale plants, in water collecting areas, particularly on shallow duplex soils (Photo 9).
- Wet soil and/or water-loving weeds present.
- Early plant senescence in waterlogging prone areas.

Photo 9: *Pale plants in waterlogged areas.*

Source: DAFWA

Plant

- Plants are particularly vulnerable from seeding to tillering, with seminal roots being more affected than later forming nodal roots.
- Waterlogged seed will be swollen and may have burst.
- Seedlings may die before emergence or be pale and weak.
- Waterlogged plants appear to be nitrogen deficient with pale plants, poor tillering, and older leaf death.
- If waterlogging persists, roots (particularly root tips) cease growing, become brown and then die (Photo 10).
- Seminal roots are important for accessing deep subsoil moisture. If damaged by waterlogging the plants may be more sensitive to spring drought.

Photo 10: *Waterlogged roots (particularly seminal roots and tips) become brown and then die.*

Source: DAFWA

How can waterlogging be monitored?

- Water levels can be monitored with bores or observation pits, but water tables can vary greatly over short distances.
- Plants can be waterlogged if there is a water table within 30 cm of the surface and no indication of waterlogging at the surface. Observe plant symptoms and paddock clues and verify by digging a hole. [30]

Other impacts of waterlogging and flood events

Heat from stagnant water

Stagnant water, particularly if shallow, can heat up in hot sunny weather and kill plants in a few hours. Remove excess water as soon as possible after flooding to give plants the best chance of survival.

Chemical and biological contaminants

Floodwater may carry contaminants, particularly from off-farm run-off. You should discard all produce exposed to off-farm run-off, particularly leafy crops.

Make sure you take food safety precautions and test soils before replanting, even if crops look healthy. Contaminants will reduce over time with follow-up rainfall and sunny weather.

30 DAFWA (2015) Diagnosing waterlogging in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

Iron chlorosis or nitrogen deficiency

Floods and high rainfall can leach essential nutrients from the soil, which can affect plant health. Nutrients such as iron and nitrogen can be replaced through the use of fertiliser.

Soils with high clay content

High clay content means soils can become compacted and form a surface crust after heavy rainfall and flooding. Floodwater also deposits a fine clay layer or crust on top of the soil, which prevents oxygen penetration into the soil (aeration). This layer should be broken up and incorporated into the soil profile as soon as possible.

Pests and diseases

Many diseases are more active in wet, humid conditions and pests can also cause problems. Remove dying or dead plants that may become an entry point for disease organisms or insect pests. Apply suitable disease control measures as soon as possible and monitor for pests. [31]

Flooding and disease

The environment influences disease incidence, frequency and duration through moisture, 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. Rainfall and flooding can transport of inoculum (crown rot, nematodes, leaf spots through movement of infected stubble and soil) and can weather-damage seed. [32]

Soil erosion due to flooding

Maintenance of productive soil base by minimising soil erosion is vital to long term crop production. Flood events will often cause damaging soil erosion. A number of approaches can be used to prevent soil erosion during flooding. 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. [33]

Weed emergence following floods

Floodwater affects soil, stubble, weed seed and plant movement. Growers might expect to see new weed incursions and removal of topsoil caused by flooding. There is also the potential for the introduction and movement of herbicide-resistant weeds. The removal of topsoil could lead to the exposure of previously buried weed seed. It is hard to predict where weed seeds will settle, but a concentration is likely where water and trash have settled. [34] Growers should monitor for weed outbreaks following floods and take necessary weed management action.

VIDEOS

WATCH: GCTV3: Big Wet—Managing strategies after flooding.

14.2.3 Managing waterlogging

Key points

- Sow waterlogging tolerant crops such as oats and faba beans.
- Sow as early as possible with a higher cereal seeding rate.
- Drainage may be appropriate on sandy duplex soils on sloping sites.

31 Queensland Government (2016) Managing risks to waterlogged crops, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/managing-risks-waterlogged-crops

32 DAFQ (2013) Winter cereals pathology. Department of Agriculture and Fisheries Queensland, January 2013, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/winter-cereals-pathology

33 DAFQ (2013) Soil erosion and waterlogging due to flooding. Department of Agriculture and Fisheries Queensland, January 2013, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/soil-erosion-and-waterlogging-due-to-flooding

34 DAFQ (2011) Weed management following floods. Department of Agriculture and Fisheries Queensland, May 2011, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/weed-management-following-floods

VIDEOS

WATCH: Over the Fence: Raised beds boost yields at Winchelsea.

- Raised beds are more effective on relatively flat areas and on heavier textured soils, but areas need to be large enough to justify machinery costs. [35] (For more information on raised beds see Cropping on raised beds in southern NSW).

Drainage is usually the best way of reducing waterlogging. Other management options to reduce the impact of waterlogging include: choice of crop, seeding, fertiliser and weed control.

Drain waterlogged soils as quickly as possible, and cultivate between rows to aerate the soil.

Good drainage is essential for maintaining crop health. Wet weather provides a good opportunity to improve the drainage of your crop land, as it allows you to identify and address any problem areas.

There are several things you can do to improve crop drainage, immediately and in the longer term.

Drainage problems after flooding

After significant rain or flooding, inspect the crops when it is safe to do so and mark areas (e.g. with coloured pegs) that are affected by poor drainage. If possible, take immediate steps to improve the drainage of these areas so that the water can get away (e.g. by digging drains).

Irrigation after waterlogging

To avoid recurrence of waterlogging, time irrigation by applying small amounts often until the crop's root system has recovered.

Ways to improve drainage

In the longer term, look for ways to improve the drainage of the affected areas. Options might include:

- re-shaping the layout of the field
- improving surface drainage
- installing subsurface drainage.

If the drainage can't be improved, consider using the area for some other purpose (e.g. for a silt trap). [36]

Choice of crop species, variety and seeding date

Some species of grains crop are more tolerant than others. Some grain legumes and canola are generally more susceptible to waterlogging than cereals and faba beans.

Seeding crops early and using long-season varieties help to avoid crop damage from waterlogging. Crop damage is particularly severe if plants are waterlogged between germination and emergence. Plant paddocks that are susceptible to waterlogging first. However, if waterlogging delays emergence and reduces cereal plant density to fewer than 50 plants/m^2, re-sow the crop.

Seeding rates

Increase sowing rates in areas susceptible to waterlogging to give some insurance against uneven germination, and to reduce the dependence of cereal crops on tillering to produce grain. Waterlogging depresses tillering. High sowing rates will also increase the competitiveness of the crop against weeds, which take advantage of stressed crops.

35 DAFWA (2015) Diagnosing waterlogging in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

36 Queensland Government (2016) Improving drainage of crop land, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/improving-drainage-crop-land

MORE INFORMATION

Should waterlogged crop be top-dressed with N fertiliser?

VIDEOS

WATCH: The 2012 N story and planning for 2013.

Nitrogen fertiliser

Crops tolerate waterlogging better with a good N status before waterlogging occurs. Applying N at the end of a waterlogging period can be an advantage if N was applied at or shortly after seeding, because it avoids loss by leaching or denitrification. However, N cannot usually be applied from vehicles when soils are wet, so consider aerial applications.

If waterlogging is moderate (seven to 30 days waterlogging to the soil surface), then N application after waterlogging events when the crop is actively growing is recommended where basal N applications were 0–50 kg N/ha. However, if waterlogging is severe (greater than 30 days to the soil surface), then the benefits of N application after waterlogging are questionable. But this recommendation requires verification in the field at a range of basal N applications using a selection of varieties.

Weed density affect a crop's ability to recover from waterlogging. Weeds compete for water and the small amount of remaining N, hence the waterlogged parts of a paddock are often weedy and require special attention if the yield potential is to be reached. [37]

14.3 Other climatic and abiotic issues

Water availability and heat stress are major limiting factors to wheat yield and grain quality. [38] Table 7 details the effects of various rainfall and temperature variables at both flowering and grainfill on crop yield in south eastern Australia.

Table 6: *The effect of various climatic variables on grain yield across over 600 field experiments in southern Australia, 2005–2010. The average grain yield across all trials was 2,530 kg/ha.*

Growth stage	Climatic variable	Unit	Effect (kg/ha)
Flowering	Rainfall	mm	+22
	Average daily minimum temperature	°C	-161
	Average daily maximum temperature	°C	-371
	Days >30°C	number	-379
	Average temperature	°C	-490
	Days >35°C	number	-837
Grainfilling	Rainfall	mm	+23
	Average daily minimum temperature	°C	-125
	Days >30°C	number	-130
	Days >35°C	number	-179
	Average daily maximum temperature	°C	-225
	Average temperature	°C	-224

Source: Grains Research and Development Corporation

37 DAFWA (2015) Management to reduce the impact of waterlogging in crops, https://www.agric.wa.gov.au/waterlogging/management-reduce-impact-waterlogging-crops

38 M Sissons, B Ovenden, D Adorada, A Milgate (2014) Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

14.3.1 Heat stress

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 during reproductive growth. Field data suggest that yield losses can be in the order of 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. [39]

In one study, heat stress was found to reduce grain yield and 1000-grain weight in durum by 33% and 42%, respectively. [40]

The reproductive stages of growth have greater sensitivity to elevated temperatures, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seed set, 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. [41]

In some cereals heat stress can be identified by the withering and splitting of leaf tips (Photo 11). Tips of the leaves can also turn brown to grey in colour. Some or all grains fail to develop in a panicle. [42]

Photo 11: *Withered and split tips in heat stressed cereal.*

Source: DAFWA

MORE INFORMATION

Assessing and managing heat stress in cereals

14.3.2 Sodicity and salinity

Sodicity (exchangeable sodium >6%) occurs on over 80% of cropping land in Victoria and over 60% of cropping lands in Australia. Sodic soils have poor soil structure and porosity which limits available water and reduces plant growth by up to 50%. Similarly,

39 AS Dias, J Semedo, JC Ramalho, FC Lidon (2011). Bread and durum wheat under heat stress: a comparative study on the photosynthetic performance. Journal of Agronomy and Crop Science, 197(1), 50–56, http://onlinelibrary.wiley.com/doi/10.1111/j.1439-037X.2010.00442.x/abstract

40 Modhej, A., Naderi, A., Emam, Y., Aynehband, A., & Normohamadi, G. (2012). Effects of post-anthesis heat stress and nitrogen levels on grain yield in wheat (T. durum and T. aestivum) genotypes. *International Journal of Plant Production*, *2*(3), 257-268.

41 P Telfer, J Edwards, H Kuchel, J Reinheimer, D Bennett (2013) Heat stress tolerance of wheat. GRDC update papers. Grains Research and Development Corporation, February 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Heat-stress-tolerance-of-wheat

42 DAFWA. (2016). Diagnosing heat stress in oats. https://www.agric.wa.gov.au/mycrop/diagnosing-heat-stress-oats

soil salinity occurs extensively in Victoria and the cropping regions of SA. Like sodic soil, saline soils also have excessive amounts of sodium however saline soil also contain other salts, namely calcium and magnesium as well as chloride, sulphate and carbonates. Since both salinity and sodicity is related to a soil's sodium content, soil is classified along a spectrum from saline to sodic.

Salinity that affects crop growth is associated with water tables and susceptibility to waterlogging in south-east SA, whilst most cropped soils in Victoria and SA have the potential to experience transient salinity associated with excess rainfall occurring in sodic soils. The economic effect of salinity in agriculture is considerable, being estimated at $1.5 billion annually for the whole of Australia. An exception is in the higher rainfall environment of southern Victoria where salinity is not considered a major factor effecting productivity of grain crops. [43]

In one study, durum wheat was grown in artificially created saline and sodic soils. Although salinity resulted in the largest decreases in seedling emergence and survival, sodicity especially at high level caused 22% and 86% decreases in plant height and grain yield respectively. The decreases in grain yield at high salinity and high sodicity were mainly due to decreases in the number of grains per plant and mean grain mass and were associated with 29% increased concentration of Na+ and 94% lower K+/Na+ ratio over control in flag leaf sap. These effects were greater at high sodicity, where the external Na+ concentration was higher than at high salinity. [44]

Symptoms of salinity

Paddock

- Moist bare patches where seed has failed to germinate or seedlings have died (Photo 12).
- Patches of stunted and apparently water stressed or prematurely dead plants in areas subject to salinity.
- Most crop weeds will also be affected with the exception of salt tolerant species.
- Salt crystals may occur on dry soil surface.

43 CropPro. Physical and chemical soil constraints of wheat crops in southern Australia. CropPro Diagnostic Agronomy,

44 Rajper, I., Wright, D., & Sial, N. B. (2003). Effect of soil salinity and sodicity on the growth and yield of durum wheat (Triticum turgidum L.) genotypes. *Pakistan Journal of Agriculture: Agricultural Engineering Veterinary Sciences (Pakistan).*

Photo 12: *Bare saline area with surviving plants dying prematurely.*

Source: DAFWA

Plant

- Plants have a harsh droughted appearance, and may be smaller with smaller dull leaves (Photo 13).
- Old leaves develop dull yellow tips and die back from the tips and edge.
- Heads are smaller with small grain.
- Plants die prematurely.
- Root growth is reduced, and may be brown and poorly branched or die if the plant is also waterlogged.

Photo 13: *Surviving plants appear to be limp and water stressed.*

Source: DAFWA

Management strategies

- Naturally saline soils cannot be ameliorated but managed according to season and their capability.
- Engineering solutions such as drainage may be possible for secondary salinity but must be assessed on a site-by-site basis.
- Barley is the most salt tolerant cereal, but it has poor waterlogging tolerance. [45]

There are no simple solutions for managing salinity and there is no 'quick fix'. Salinity inducing processes are complex, whether on a farm or in an urban environment.

General information is available on the management of salinity for urban, dryland and irrigation land uses. However, the expertise of technical specialists will help ensure that salinity management actions are appropriate for the specific location and set of conditions.

Managing groundwater levels

Salinity management aims to maintain groundwater levels at least 2 m below the soil surface, mainly by maximising plant water use to reduce groundwater recharge. Useful techniques include:

- Monitoring groundwater levels.
- Growing species tolerant of salt and waterlogging in low lying, non-production areas.
- Growing perennial pastures as these can use twice as much water as annual pastures.
- Avoiding long fallows when the profile is >75% of field capacity.

45 DAFWA (2015) Diagnosing salinity in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-salinity-cereals

- Appropriate crop selection and crop rotations.
- Efficient irrigation management.

Troubleshooting

Recognising and acting on salinity problems early is the best solution, as soil salinity can be a more difficult and expensive issue to correct when well advanced.

Dryland salinity outbreaks can be managed by excluding grazing on saline areas and sowing saline tolerant species.

Irrigation salinity can be managed by improving irrigation management, specifically application efficiency.

Specific management of salt-affected areas could include hill/bed shapes that minimise salt accumulation around seedlings, and pumping and recycling of groundwater (this requires advice from a hydrology consultant). [46]

MORE INFORMATION

Preventing and managing salinity

Managing saline soils.

46 Soilquality.org. Salinity—NSW, http://soilquality.org.au/factsheets/salinity-nsw

Marketing

The final step in generating farm income is converting the tonnes produced into dollars at the farm gate. This section provides best in class marketing guidelines for managing price variability to protect income and cash-flow.

Figure 1 shows a grain selling flow chart that summarises:

- The decisions to be made.
- The drivers behind the decisions.
- The guiding principles for each decision point.

The reference column refers to the section of the GrowNote where you will find the details to help in making decisions.

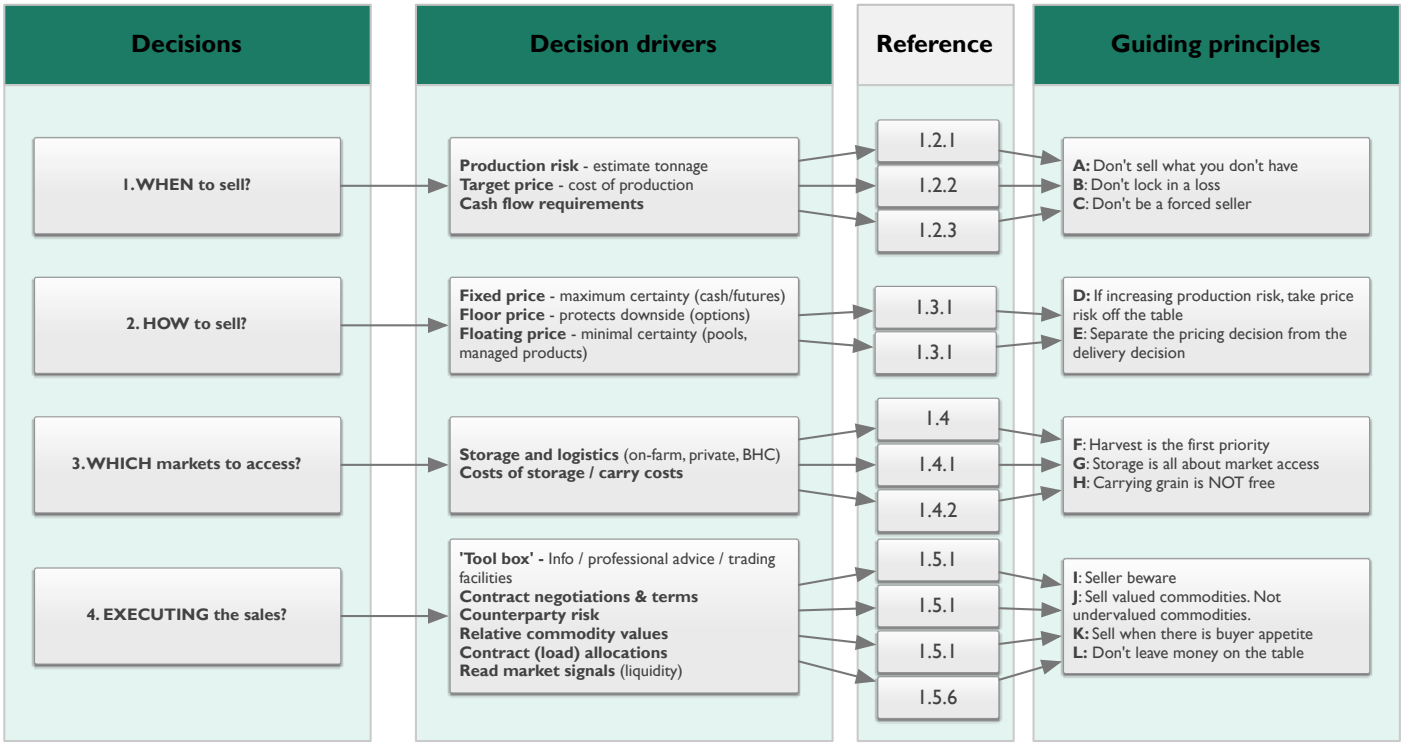


Figure 1: *Grain-selling flowchart.*

The grower will run through a decision-making process each season, because growing and harvesting conditions, and prices for grains, change all the time. For example, in the seven years to 2015, Port Adelaide durum values varied by as much as A$310/t, (representing variability of 35–80%) (Figure 2). For a property producing 500 tonnes of durum this means $50,000–$155,000 difference in income, depending on the timing of sales.

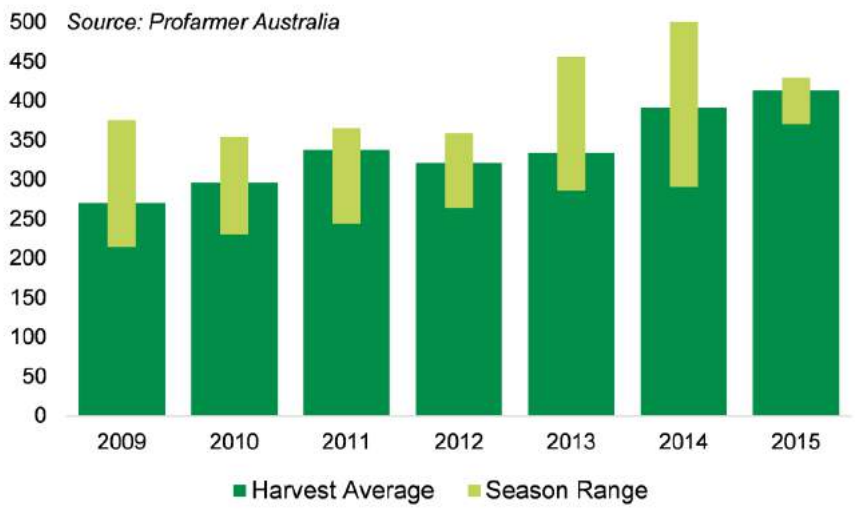


Figure 2: *Intra-season variance of Port Adelaide durum values.*

Source: Profarmer Australia

15.1 Selling principles

The aim of a selling program is to achieve a profitable average price (the target price) across the entire business. This requires managing several unknowns to establish a target price and then work towards achieving the target price.

Unknowns include the amount of grain available to sell (production variability), the final cost of producing the grain, and the future prices that may result. Australian farm-gate prices are subject to volatility caused by a range of global factors that are beyond our control and are difficult to predict.

The skills growers have developed to manage production unknowns can also be used to manage pricing unknowns. This guide will help growers manage and overcome price uncertainty.

15.1.1 Be prepared

Being prepared by having a selling plan is essential for managing uncertainty. The steps involved are forming a selling strategy, and forming a plan for effectively executing sales. The selling strategy consists of when and how to sell

When to sell

Knowing when to sell requires an understanding of the farm's internal business factors, including:

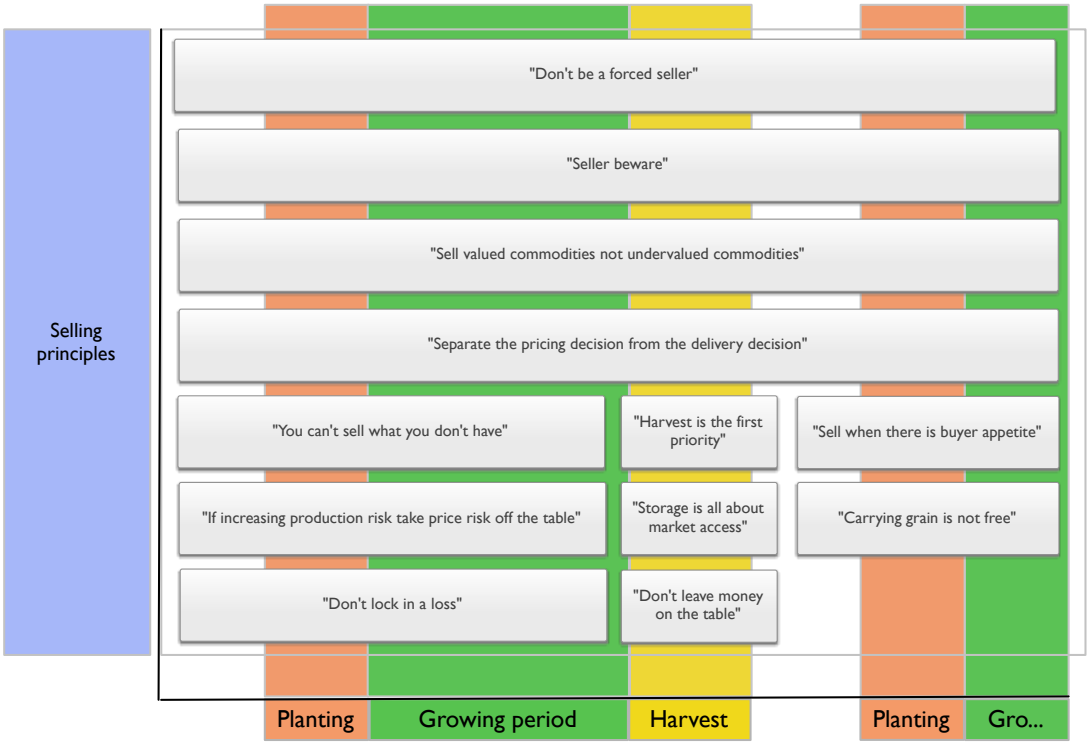
- production risk
- a target price based on the cost of production and the desired profit margin
- business cashflow requirements

How to sell

Working out how to sell your grain is more dependent on external market factors, including:

- the time of year, which determines the pricing method
- market access, which determines where to sell
- relative value, which determines what to sell

The following diagram (Figure 3) lists the key selling principles to employ when considering sales during the growing season. Exactly when each principle comes into play is indicated in the text of section 15.



Note to figure:
The illustration demonstrates the key selling principles throughout the production cycle of a crop.

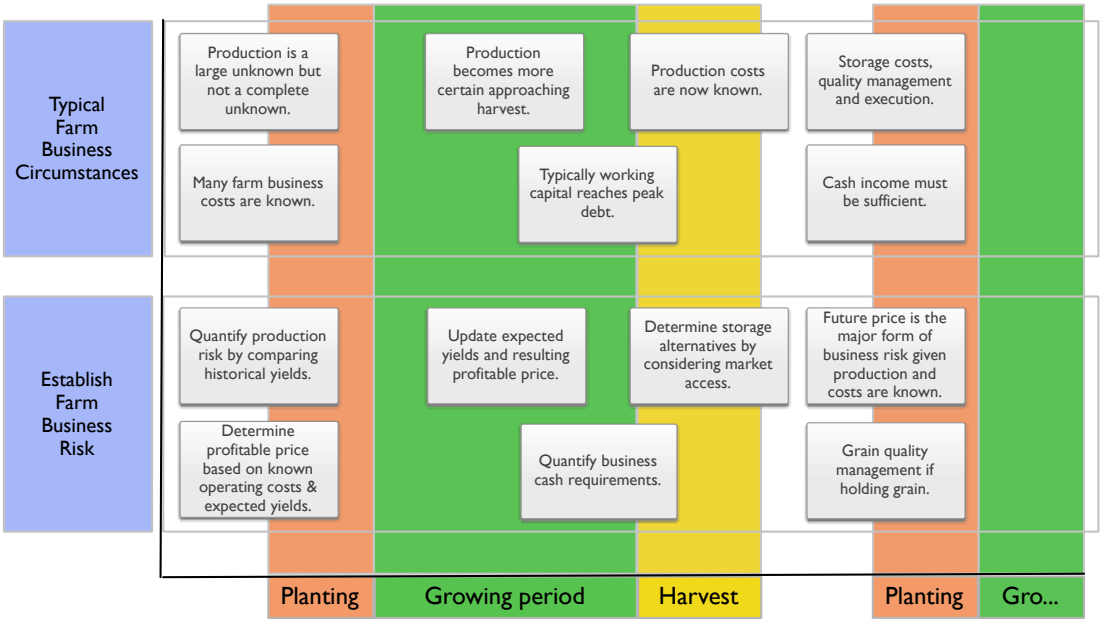
Profarmer AUSTRALIA

Figure 3: *Timeline of grower commodity selling principles.*

Source: Profarmer Australia

15.1.2 Establish the business risk profile

Establishing your business risk profile helps you determine when to sell: it allows you to develop target price ranges for each commodity, and provides confidence to sell when the opportunity arises. Typical business circumstances and how to quantify the risks during the production cycle are described below (Figure 4).



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?

Profarmer AUSTRALIA

Figure 4: *Typical farm business circumstances and risk.*

Source: Profarmer Australia

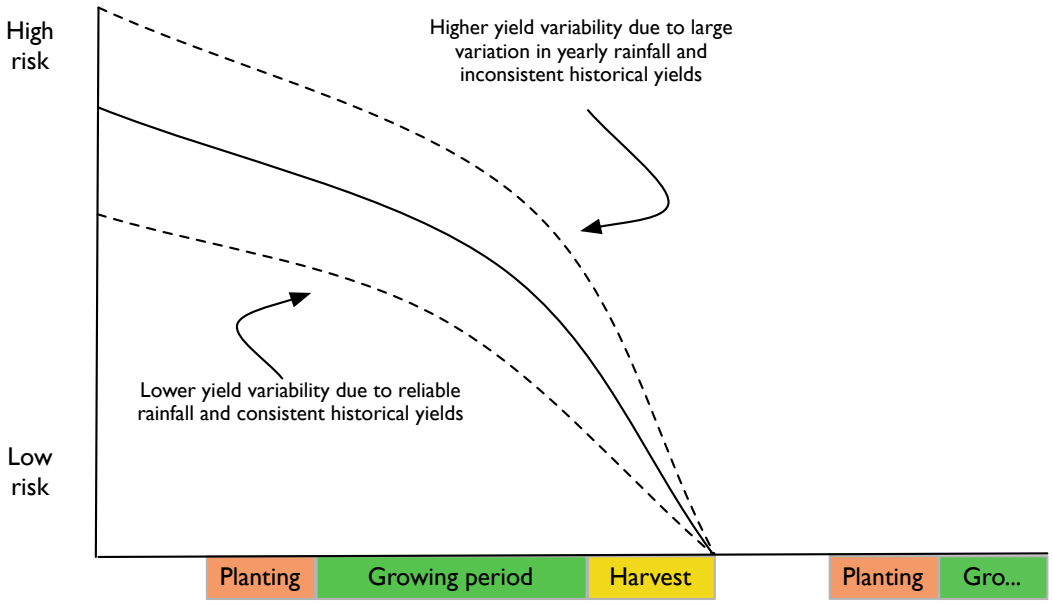
Production risk profile of the farm

Production risk is the level of certainty around producing a crop and is influenced by location (climate, season and soil type), crop type, crop management, and the time of the year.

Principle: You can't sell what you don't have.

Therefore, don't increase business risk by over committing production. Establish a production risk profile (see Figure 5) by:

1. Collating historical average yields for each crop type and a below-average and above-average range.
2. Assessing the likelihood of achieving the average, based on recent seasonal conditions and the seasonal outlook.
3. Revising production outlooks as the season progresses.



Note to figure:
The quantity of crop grown is a large unknown early in the year however not a complete unknown. 'You can't sell what you don't have' but it is important to compare historical yields to get a true indication of production risk. This risk reduces as the season progresses and yield becomes more certain. Businesses will face varying production risk levels at any given point in time with consideration to rainfall, yield potential, soil type, commodity etc.

Profarmer AUSTRALIA

Figure 5: *Typical risk profile of a farm operation.*

Source: Profarmer Australia

Establishing a target price

A profitable commodity target price is the cost of production per tonne plus a desired profit margin. It is essential to know the cost of production per tonne for the farm business, which means knowing all farm costs, both variable and fixed.

Principle: Don't lock in a loss.

If committing production ahead of harvest, ensure the price will be profitable. The steps needed to calculate an estimated profitable price is based on the total cost of production and a range of yield scenarios, as provided below (Figure 6).

Estimating cost of production - 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
Receival fees	$11 /t
Freight to Port	$22 /t
Total per tonne costs	$48 /t
Cost of production Port FIS equiv	$259.20
Target profit (ie 20%)	$52.00
Target price (port equiv)	**$311.20**

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 6: *An example of how to estimate the costs of production.*

Source: GRDC's manual Farming the Business also provides a cost-of-production template and tips on grain selling v. grain marketing.

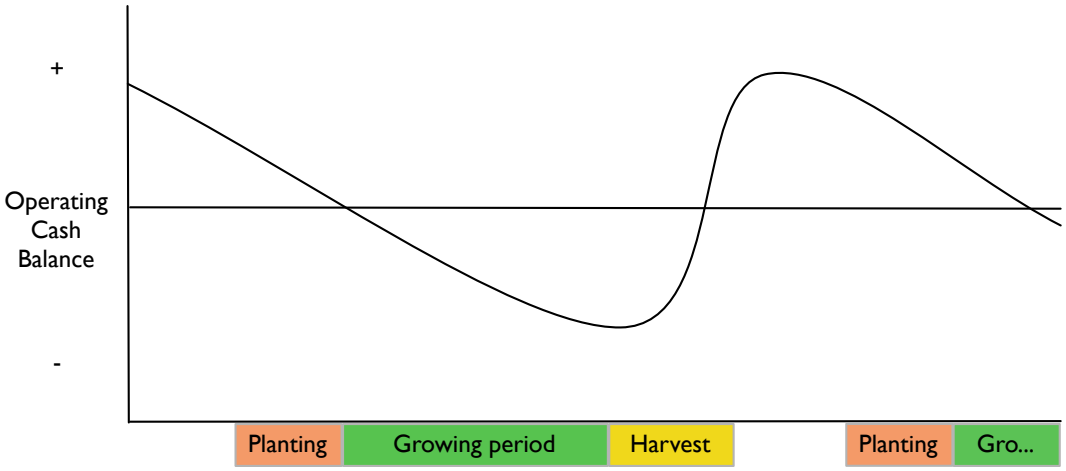
Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables growers to time grain sales so that cash is available when required. This prevents having to sell grain below the target price to satisfy a need for cash.

Principle: Don't be a forced seller.

Be ahead of cash requirements to avoid selling in unfavourable markets.

Typical cash-flow to grow a crop are illustrated below (Figures 7 and 8). Costs are incurred up front and during the growing season, with peak working capital debt incurred at or before harvest. Patterns will vary depending on circumstance and enterprise mix. The second figure demonstrates how managing sales can change the farm's cash balance.



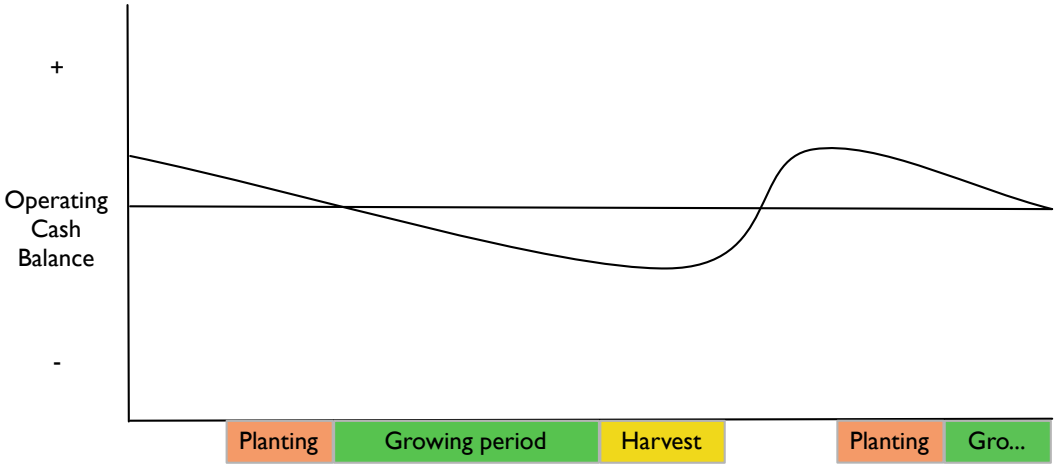
In this scenario peak cash surplus starts higher and peak cash debt is lower

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.

Profarmer AUSTRALIA

Figure 7: *Typical operating cash balance.*

Source: Profarmer Australia



In this scenario peak cash surplus starts lower and peak cash debt is higher

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.

Profarmer AUSTRALIA

Figure 8: *Typical operating cash balance.*

Source: Profarmer Australia

The when-to-sell steps above result in an estimated production tonnage and the risk associated with producing 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

The first part of the selling strategy answers the question about when to sell and establishes comfort around selling a portion of the harvest.

The second part of the strategy, managing your price, addresses how to sell your crop.

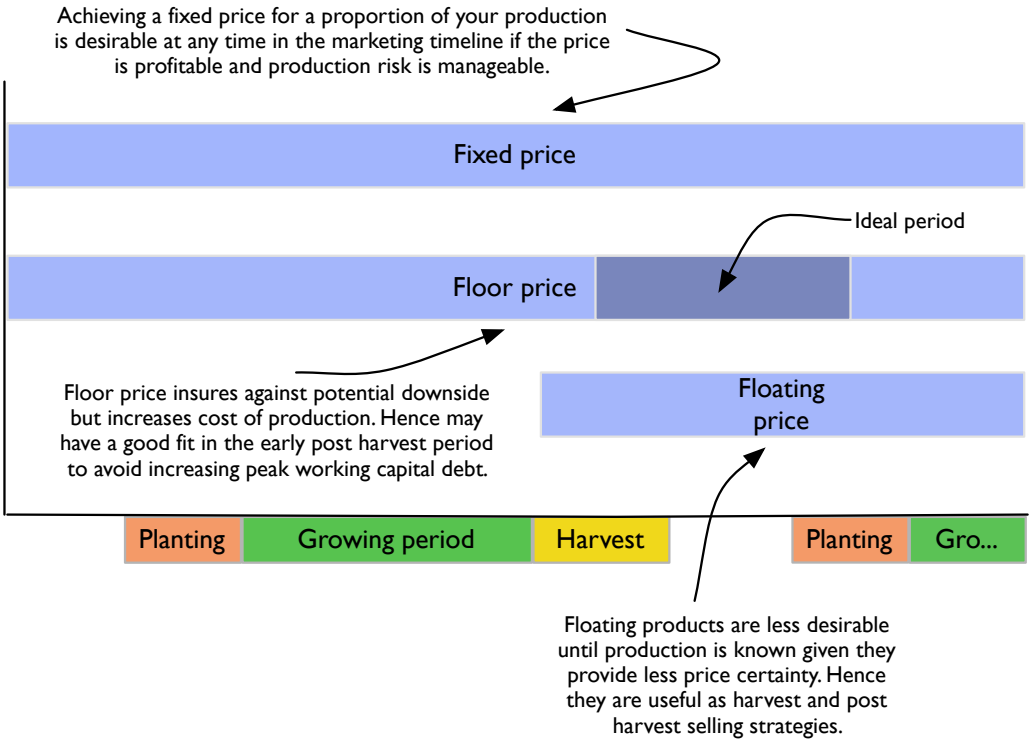
Methods of price management

Pricing products provide varying levels of price risk coverage (Table 1).

Table 1: *Pricing methods and how they are used for different 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 9 summarises how the different methods of price management are suited to the majority of farm businesses.



Note to figure: Different price strategies are more applicable through varying periods of the growing season. If selling in the forward market growers are selling something not yet grown hence the inherent production risk of the business increases. This means growers should achieve price certainty if committing tonnage ahead of harvest. Hence fixed or floor products are favourable. Comparatively a floating price strategy may be effective in the harvest and post harvest period.

Profarmer AUSTRALIA

Figure 9: *Price strategy timeline, summarising the suitability for most farm businesses of different methods of price management for different phases of production.*

Source: Profarmer Australia

Principle: If increasing production risk, take price risk off the table.

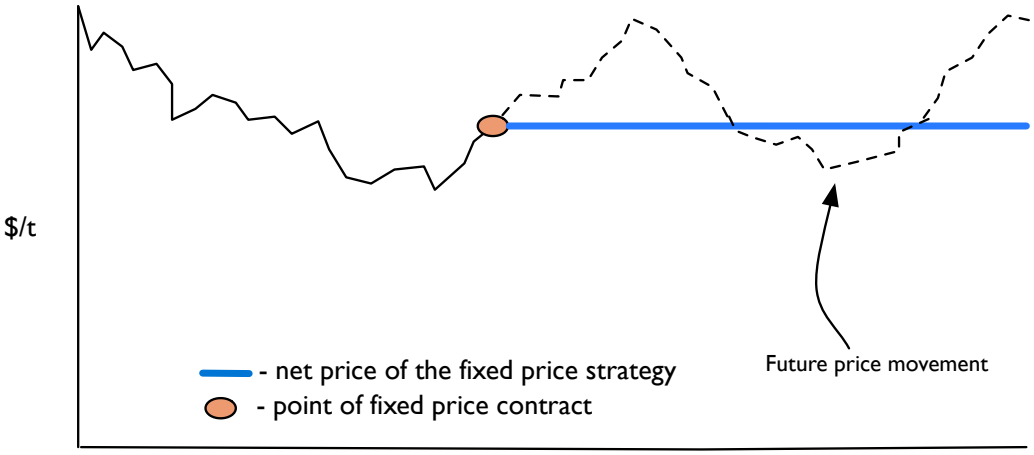
When committing to unknown production, price certainty should be achieved to avoid increasing overall business risk.

Principle: Separate the pricing decision from the delivery decision.

Most commodities can be sold at any time with delivery timeframes being negotiable, hence price management is not determined by delivery.

Fixed price

A fixed price is achieved via cash sales and/or selling a futures position (swaps) (Figure 10). It provides some certainty around expected revenue from a sale as the price is largely a known factor, except when there is a floating component in the price, e.g. a multi-grade cash contract with floating spreads or a floating-basis component on futures positions.



Note to figure:
Fixed price product locks in price and provides certainty over what revenue will be generated regardless of future price movement.

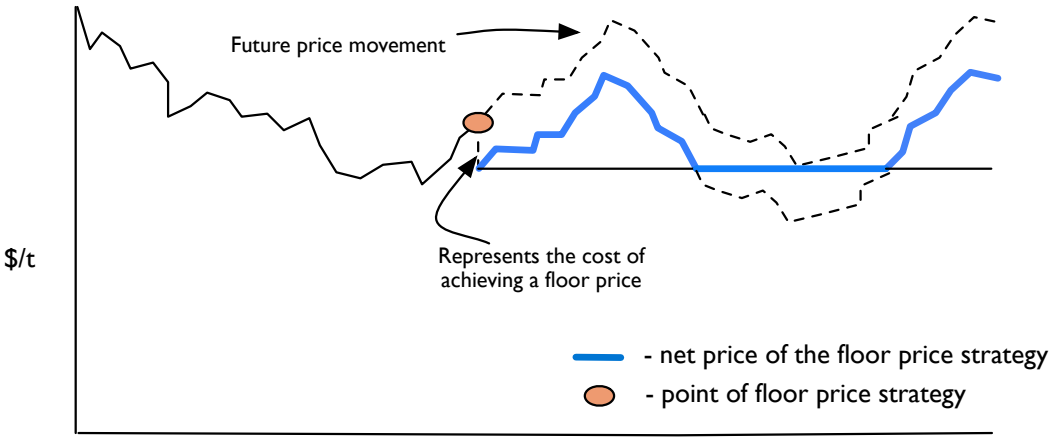
Profarmer AUSTRALIA

Figure 10: *Fixed price strategy.*

Source: Profarmer Australia

Floor price

Floor-price strategies (Figure 11) can be achieved by utilising options on a relevant futures exchange (if one exists), or via a managed-sales program (i.e. a pool with a defined floor price strategy) offered by a third party. This pricing method protects against potential future downside whilst capturing any upside. The disadvantage is that the price 'insurance' has a cost, which adds to the farm's cost of production.



Note to figure:
A floor price strategy insures against potential future downside in price while allowing price gains in the event of future price rallies.

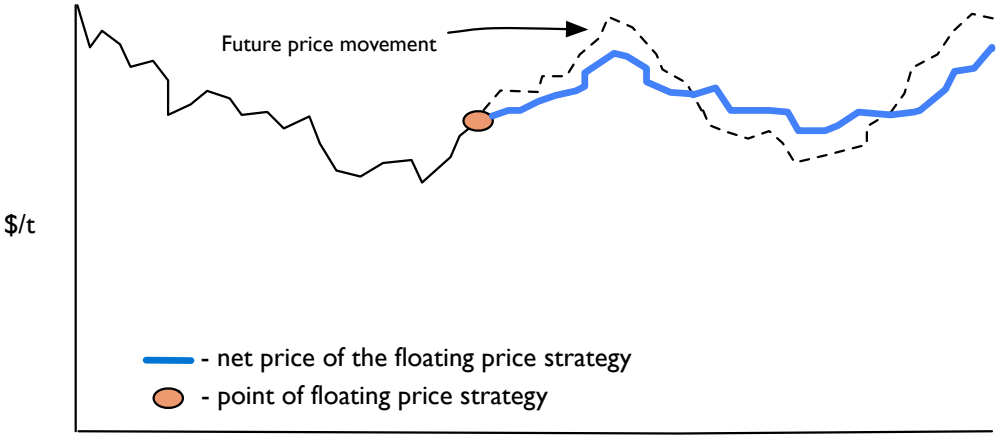
Profarmer AUSTRALIA

Figure 11: *Floor price strategy.*

Source: Profarmer Australia

3. Floating price

Many of the pools or managed-sales programs are a floating price, where the net price received will move up and down with the future movement in price (Figure 12). Floating-price products provide the least price certainty and are best suited for use at or after harvest rather than before harvest.



Note to figure:
A floating price will move to some extent with future price movements.

Profarmer AUSTRALIA

Figure 12: *Floating price strategy.*

Source: Profarmer Australia

Having considered the variables of production for the crop to be sold, and how these fit against the different pricing mechanism, the farmer may revise their selling strategy.

Fixed-price strategies include physical cash sales or futures products, and provide the most price certainty, but production risk must be considered.

Floor-price strategies include options or floor-price pools. They provide a minimum price with upside potential and rely less on production certainty, but cost more.

Floating-price strategies provide minimal price certainty, and so are best used after harvest.

15.1.4 Ensuring access to markets

Once the questions of when and how to sell are sorted out, planning moves to the storage and delivery of commodities to ensure timely access to markets and execution of sales. Planning where to store the commodity is an important component of ensuring the type of access to the market that is likely to yield the highest return (Figure 13).

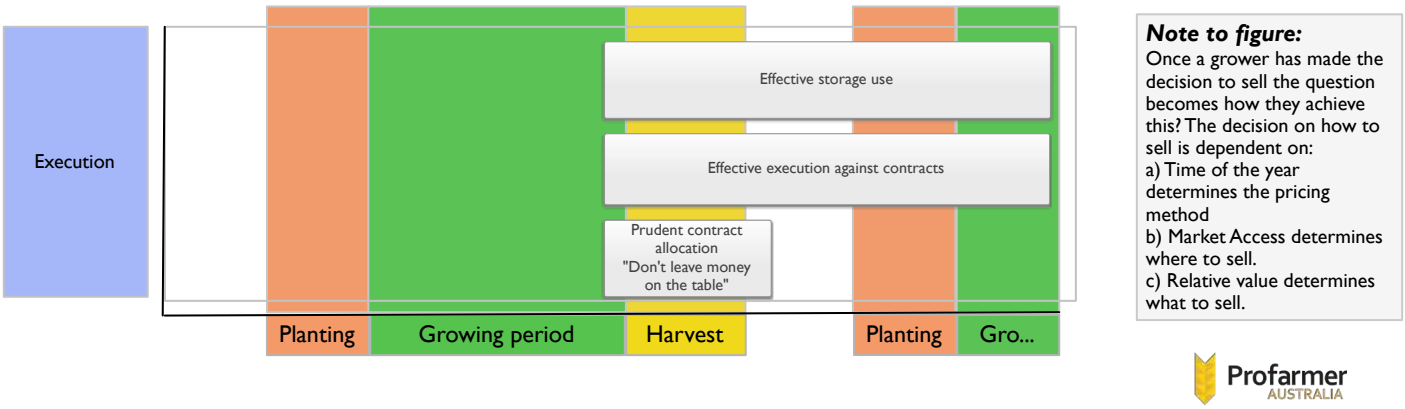


Figure 13: *How storage decisions affect selling time, and must be accommodated as part of the timing of all farming practices.*

Source: Profarmer Australia

Storage and logistics

The return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access so as to maximise returns as well as harvest logistics.

Storage alternatives include variations of bulk handling, private off-farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity (Figure 14).

Principle: Harvest is the first priority.

During harvest, getting the crop into the bin is the most critical aspect of business success; hence storage, sale and delivery of grain should be planned well ahead of harvest to allow the grower to focus on the harvest itself.

Bulk export commodities requiring significant quality management are best suited to the bulk-handling system. Commodities destined for the domestic end-user market, (e.g. feedlot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on the farm requires prudent quality management to ensure that the grain is delivered to the agreed specifications. If not well planned and carried out, it can expose the business to high risk. Penalties for out-of-specification grain arriving at a buyer's weighbridge can be expensive, as the buyer has no obligation to accept it. This means the grower may have to incur the cost of taking the load elsewhere, and may also have to find a new buyer.

On-farm storage also requires prudent delivery management to ensure commodities are received by the buyer on time and with appropriate weighbridge and sampling tickets.

Principle: Storage is all about market access.

Storage decisions depend on quality management and expected markets.

MORE INFORMATION

For more information on on-farm storage alternatives and economics refer to Section 13: Grain Storage.

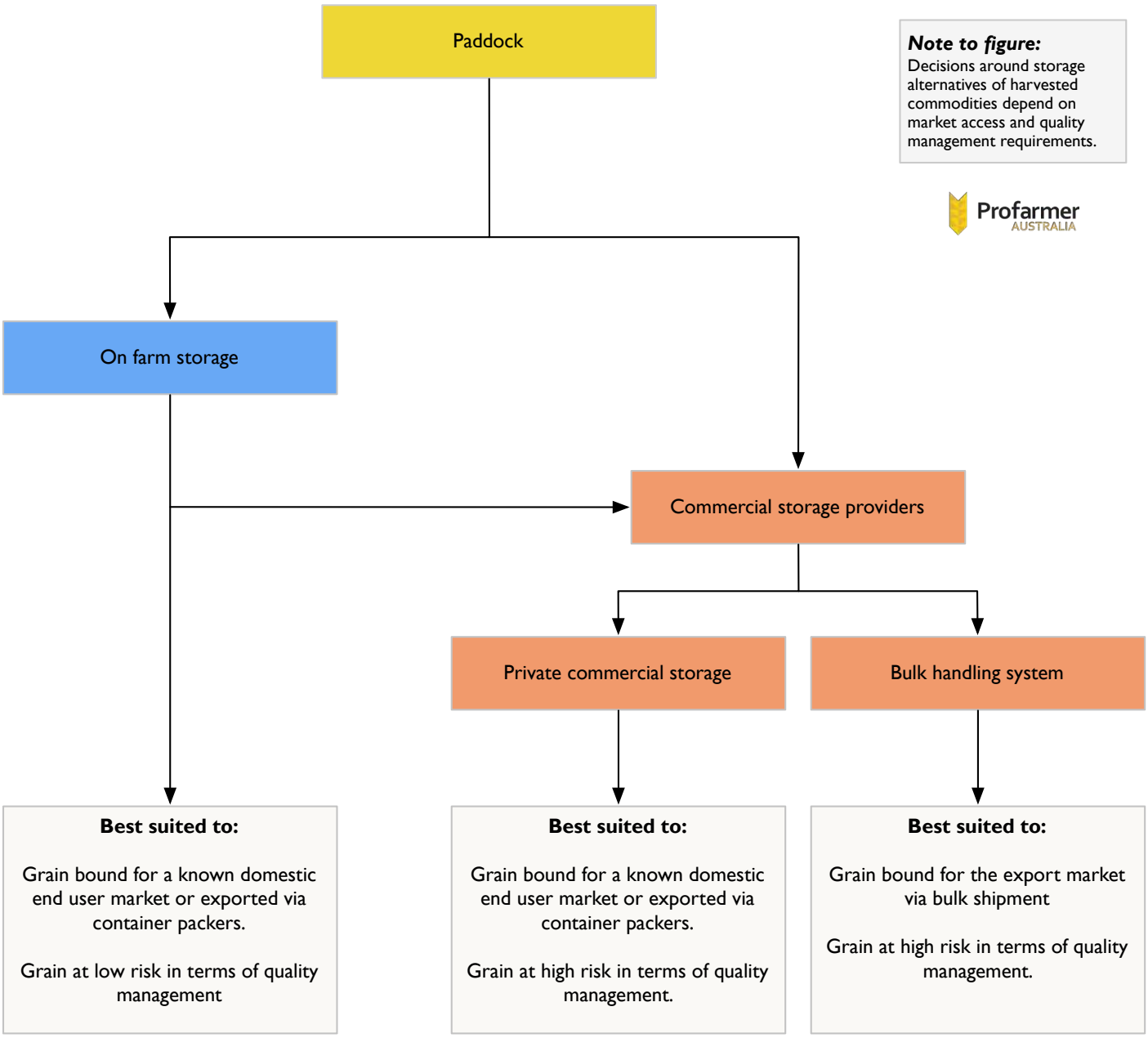


Figure 14: *Grain storage decision-making.*

Source: Profarmer Australia

Cost of carrying grain

Storing grain to access sales opportunities post-harvest invokes a cost to 'carry', or hold, the grain (Figure 15). Price targets for carried grain need to account for the cost of carrying it. Carrying costs are typically $3–4/t per month and consist of:

- Monthly storage fee charged by a commercial provider (typically ~$1.50–2.00/t).
- Monthly interest associated with having wealth tied up in grain rather than available as cash or for paying off debt (~$1.50-$2.00/t, depending on the price of the commodity and interest rates).

The price of carried grain therefore needs to be $3–4/t per month higher than the price offered at harvest.

The cost of carrying also applies to grain stored on the farm, as there is the cost of the capital invested in the farm storage plus the interest component. A reasonable assumption is a cost of $3–4/t per month for on-farm storage.

Principle: Carrying grain is not free.

The cost of carrying grain needs to be accounted for if holding it for sale after harvest is part of the selling strategy.

If selling a cash contract with deferred delivery, a carrying charge can be negotiated into the contract. For example, a March sale of canola for March–June delivery on the buyers call at a price of $300/t + $3/t carrying per month, would generate revenue of $309/t delivered in June.

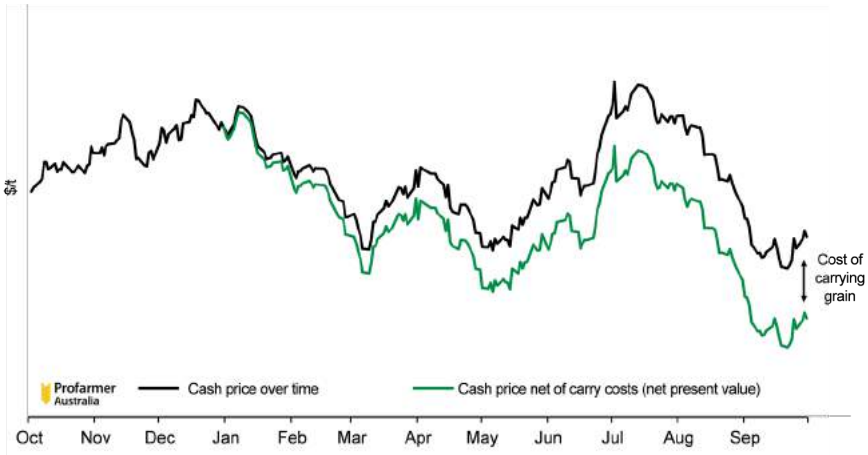


Figure 15: *Cash values v. cash adjusted for the cost of carrying.*

Source: Profarmer Australia

Optimising farm-gate returns involves planning the appropriate storage strategy for each commodity to improve market access and ensure that carrying costs are covered in pricing decisions.

15.1.5 Converting tonnes into cash

This section provides guidelines for converting the selling and storage strategy into cash by effective execution of sales.

Set up the toolbox

Selling opportunities can be captured when they arise by assembling the necessary tools in advance. The toolbox for converting tonnes of grain into cash includes the following.

1. Timely information

This is critical for awareness of selling opportunities and includes:

- Market information provided by independent parties.
- Effective price discovery including indicative bids, firm bids, and trade prices.
- Other market information pertinent to the particular commodity.

2. Professional services

Grain-selling professional 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. A better return on investment for the farm business is achieved through higher farm-gate prices that are obtained by accessing timely information, and the seller's greater market knowledge and greater market access.

MORE INFORMATION

Access to buyers, brokers, agents, products and banks through Grain Trade Australia

Commodity futures brokers

ASX's Find a futures broker

3. Futures account and a bank-swap facility

These accounts provide access to global futures markets. Hedging futures markets is not for everyone; however, strategies which utilise exchanges such as the Chicago Board of Trade (CBOT) can add significant value.

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 16):

- Price—future price is largely unpredictable, so devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.
- Quantity and quality—when entering a cash contract, you are committing to deliver the nominated amount of grain at the quality specified, so production and quality risks must be managed.
- Delivery terms—the timing of the title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end-users, it relies on prudent execution management to ensure delivery within the contracted period.
- Payment terms—in Australia, the traditional method of contracting requires title on the grain to be transferred ahead of payment, so counterparty risk must be managed.

Timing of delivery (title transfer) is agreed upon at time of contracting. Hence growers negotiate execution and storage risk thy may have to manage.

Quantity (tonnage) and Quality (bin grade) determine the actuals of your commitment. Production and execution risk must be managed.

Price is negotiable at time of contracting.

Price point is important as it determines where in the supply chain the transaction will occur and so what costs will come out of the price before the growers net return.

Whilst the majority of transactions are on the premise that title of grain is transferred ahead of payment this is negotiable. Managing counterparty risk is critical.

GTA Contract No.3

CONTRACT CONFIRMATION

GTA Trade Rules and Dispute Resolution Rules apply to this contract

GRAIN TRADE AUSTRALIA

This Contract is confirmation between:

BUYER
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:

GTA Commodity Reference:
Inspection: (Origin – Destination)
Tolerance: (Refer over)
Weights: (Origin – Destination)
Excl/Inc/Free GST

Delivery/Shipment Period:
Delivery Point and Conveyance: (Delivered, Shipped, Free In Store, Free On Board, Ex-Farm, etc.)
(Port of Entry, Port of Discharge, Port of Origin, Point, Loading Weight requirements if applicable)

Payment Terms: The buyer agrees to pay the seller within . In the absence of a declaration, payment will be 30 days end of week of delivery.

Levies and Statutory Charges: Any industry, statutory or government levies which are not included in the price shall be deducted as required by law.

Disclosures: Is any of the crop referred to in this contract subject to a mortgage, Encumbrance or lien and/or Plant Breeders Rights and/or EPR liabilities and/or registered or unregistered Security Interest? ◉NO ◯YES (Please ☐ appropriate box) If "yes" please provide details:

Other Special Terms and Conditions:

All Contract Terms and Conditions as set out above and on the reverse of this page form part of this Contract. Terms and Conditions written on the face of this Contract Confirmation shall overrule all printed Terms and Conditions on the reverse with which they conflict to the extent of the inconsistency. This Contract comprises the entire agreement between Buyer and Seller with respect to the subject matter of this Contract.

Recipient Created Tax Invoice (RCTI).
To assist with the processing of the Goods and Services Tax compliance, the buyer may prepare, for the seller, a Recipient Created Tax Invoice (RCTI). If the seller requires this service they are required to sign this authorisation.
☐ Please issue a RCTI (Please ☐)

Incorporation of GTA Trade & Dispute Resolution Rules:
This contract expressly incorporates the GTA Trade Rules in force at the time of this contract and Dispute Resolution Rules in force at the commencement of the arbitration, under which any dispute, controversy or claim arising out of, relating to or in connection with this contract, including any question regarding its existence, validity or termination, shall be resolved by arbitration.

Buyer's Name: PRINT NAME
Buyer's Signature:
Date:

Seller's Name: PRINT 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

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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 16: *Typical terms of a cash contract.*

Source: Grain Trade Australia

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. Figure 17 depicts the terminology used to describe these points and the associated costs to come out of each price before growers receive their net return.

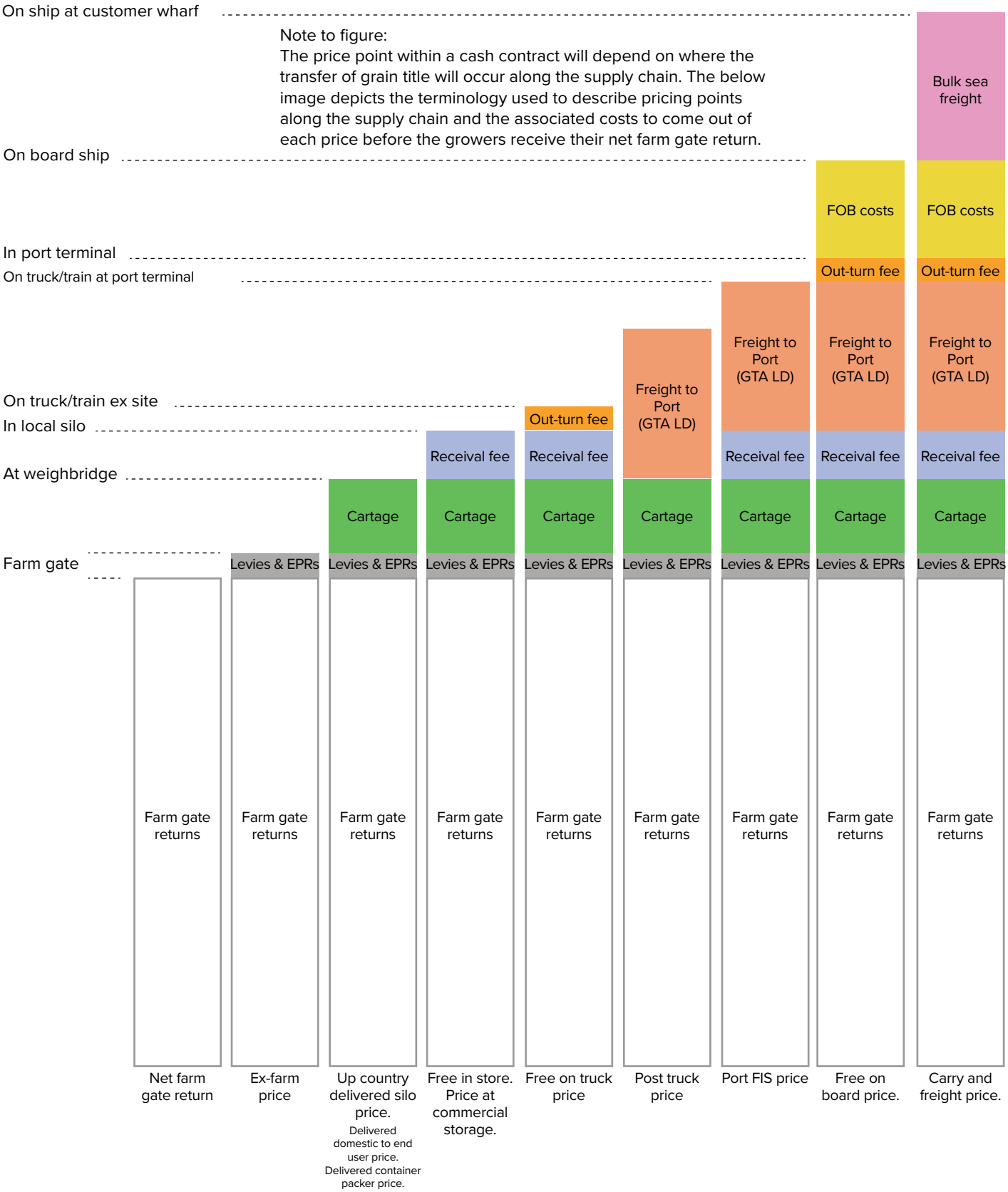


Figure 17: *Cost and pricing points throughout the supply chains.*

Source: Profarmer Australia

MORE INFORMATION

Grain Trade Australia, A guide to taking out grain contracts

Grain Trade Australia, Trading standards

GrainTransact Resource Centre

GrainFlow

Emerald Grain

Clear Grain Exchange, Getting started

Clear Grain Exchange, Terms and conditions

GTA, Managing counterparty risk

Clear Grain Exchange's title transfer model

GrainGrowers, Managing risk in grain contracts

Leo Delahunty, Counterparty risk: A producer's perspective

Cash sales generally occur through three methods:

- Negotiation via personal contact—traditionally prices are posted as a public indicative bid. The bid is then accepted or negotiated by a grower with the merchant or via an intermediary. This method is the most common and is available for all commodities.
- Accepting a public firm bid—cash prices in the form of public firm bids are posted during harvest and for warehoused grain by merchants on a site basis. Growers can sell their parcel of grain immediately by accepting the price on offer via an online facility and then transfer the grain online to the buyer. The availability of this option depends on location and commodity.
- Placing an anonymous firm offer—growers can place a firm offer price on a parcel of grain anonymously and expose it to the entire market of buyers, who then bid on it anonymously using the Clear Grain Exchange, which is an independent online exchange. If the offer and bid match, the particulars of the transaction are sent to a secure settlement facility, although the title on the grain does not transfer from the grower until they receive funds from the buyer. The availability of this option depends on location and commodity. Anonymous firm offers can also be placed to buyers by an intermediary acting on behalf of the grower. If the grain sells, the buyer and seller are disclosed to each counterparty.

Counterparty risk

Most sales involve transferring the title on the grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: Seller beware.

There is not much point selling for an extra $5/t if you don't get paid.

Counterparty risk management includes:

- Dealing only with known and trusted counterparties.
- Conducting a credit check (banks will do this) before dealing with a buyer they are unsure of.
- Selling only a small amount of grain to unknown counterparties.
- Considering credit insurance or a letter of credit from the buyer.
- Never delivering a second load of grain if payment has not been received for the first.
- Not parting with the title before payment, or requesting and receiving a cash deposit of part of the value ahead of delivery. Payment terms are negotiated at time of contracting. Alternatively, the Clear Grain Exchange provides secure settlement whereby the grower maintains title on the grain until they receive payment, and then title and payment are settled simultaneously.

Above all, act commercially to ensure the time invested in implementing a selling strategy is not wasted by poor management of counterparty risk. Achieving $5/t more on paper and not getting paid is a disastrous outcome.

Relative values

Grain-sales revenue is optimised when selling decisions are made in the context of the whole farming business. The aim is to sell each commodity when it is priced well, and to hold commodities that are not well priced at any given time. That is, give preference to the commodities with the highest relative value. This achieves price protection for the overall revenue of the farm business and enables more flexibility to a grower's selling program while achieving the business goal of reducing overall risk.

Principle: Sell valued commodities, not undervalued commodities.

If one commodity is priced strongly relative to another, focus sales there. Don't sell the cheaper commodity for a discount.

Contract allocation

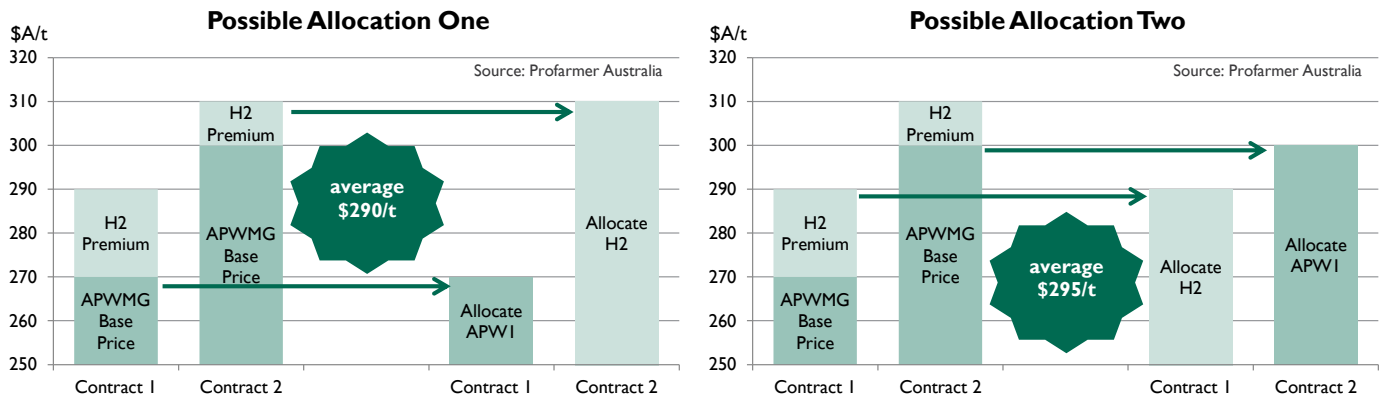
Contract allocation means choosing which contracts to allocate your grain against come delivery time. Different contracts will have different characteristics (e.g. price, premiums-discounts, oil bonuses), and optimising your allocation reflects immediately on your bottom line.

Principle: Don't leave money on the table.

Contract allocation decisions don't take long, and can be worth thousands of dollars to your bottom line.

To achieve the best average wheat price growers should:

- Allocate lower grades of wheat to contracts with the lowest discounts.
- Allocate higher grades of wheat to contracts with the highest premiums (Figure 18).



Note to figure:
In these two examples the only difference between acheiving an average price of $290/t and $295/t is which contracts each parcel was allocated to. Over 400/t that equates to $2,000 which could be lost just in how parcels are allocated to contracts.

Figure 18: *How the crop is allocated across contracts can have an impact of earnings from the crop.*

Source: Profarmer Australia

Read market signals

The appetite of buyers to buy a particular commodity will differ over time depending on market circumstances. Ideally growers should aim to sell their commodity when buyer appetite is strong, and stand aside from the market when buyers are not very interested.

Principle: Sell when there is buyer appetite.

When buyers are chasing grain, growers have more market power to demand the price they want.

Buyer appetite can be monitored by:

- The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate that buyer appetite is strong. However, if one buyer is offering $5/t above the next best bid, it may mean that cash prices are susceptible to falling $5/t if that buyer satisfies their appetite.
- Monitoring actual trades against public indicative bids. When trades are occurring above indicative public bids it may indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids. The chart below plots actual trade prices on the Clear Grain Exchange against the best public indicative bid on the day.

The selling strategy is converted to maximum business revenue by:

- Ensuring timely access to information, advice and trading facilities.
- Using different cash-market mechanisms when appropriate.
- Minimising counterparty risk by conducting effective due diligence.
- Understanding relative value and selling commodities when they are priced well.
- Thoughtful contract allocation.
- Reading market signals to extract value from the market or to prevent selling at a discount.

15.2 Southern durum: market dynamics and execution

15.2.1 Price determinants for southern durum

Durum is a specialty wheat used primarily for pasta products. Due to its specialised use, demand for durum tends to be inelastic and finite, i.e. there is a relatively fixed requirement for durum year on year, and there are few substitutes for it.

The major durum-producing regions are Canada, the European Union (predominantly France and Italy), north Africa and Australia, and the major consumers are the European Union and north Africa. Australian production is split between South Australia at 40–50% and northern NSW and southern Queensland making up the remaining 50–60% of the crop. In a typical year Australia exports 60–70% of its durum production with a small number of local food manufacturers consuming the remainder (Figure 19).

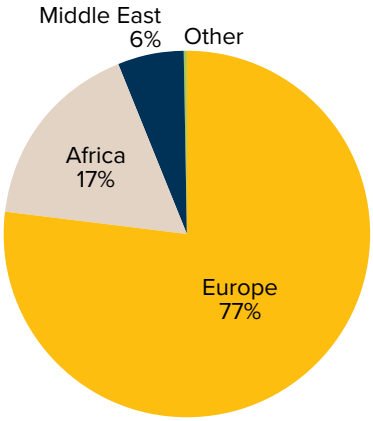


Figure 19: *Export destinations for Australian durum*

While durum values are influenced by the price of bread wheats such as APW1, these two wheat varieties ultimately have different markets and hence at times the price relativities between the two can separate reflecting differences in the supply and demand dynamics of each market. For example, during the 2014–15 season, untimely rains saw European Union durum production fall to historically low levels, and their import requirement rose to its highest level in five years. This coincided with weather-damaged crops in Canada and the United States, and with a smaller crop in Australia. Hence the production of durum wheat globally was not adequate to cover demand, and this resulted in a $200/t+ premium for durum wheat in Australia over APW1 varieties, despite an ample supply of Australian bread wheats (see Figure 20).

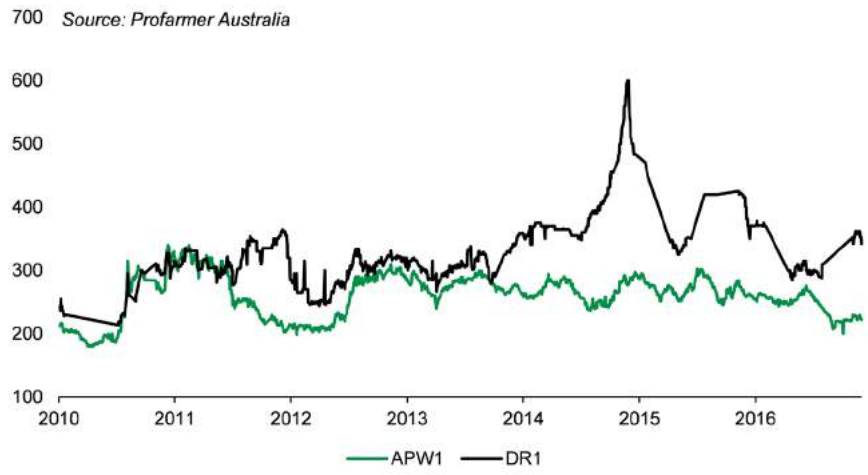


Figure 20: *Port Adelaide durum values, showing the price spike in 2014–15.*

Source: Profarmer Australia

Therefore, when global durum supply fails to meet demand, durum can trade at strong premiums compared to bread wheat as the market competes to secure their demand requirements from a smaller global crop.

However, in years when global durum supply exceeds the finite demand, Australian durum values tend to be weak relative to bread wheat varieties, as Australian durum is discounted to compete for a smaller amount of international trade activity, as well as competing for alternate homes in the domestic market (e.g. stockfeed markets).

Hence a major determinant of Australian durum values is the price at which international trade is transacting. This is influenced by:

- global supply *v.* demand
- the quality of the global crop
- the timing of the Australian export program

15.2.2 Ensuring market access for southern durum

Due to the inelastic nature of durum demand, consumers and exporters traditionally focus their accumulation programs on the period immediately leading up to, during and after harvest, when supply is the most certain. Hence the buying appetite for durum tends to be strongest from October to January. Australian durum exports are typically strongest between January and May in each marketing year, as exporters look to move the crop shortly after the Australian harvest but ahead of the harvest of the northern hemisphere crops (Figure 21).

Over 95% of durum exports are executed via bulk-export vessels rather than container exports. This makes the bulk-handling system an effective means for managing durum destined for the export market.

Being a specialty crop, there are fewer buyers of durum wheat than other grades of wheat. This means liquidity risk is a particularly important consideration for durum growers. Liquidity risk is the risk that buyers reach their accumulation requirements and step out of the market, causing the price to fall sharply, or buyer appetite to dry up altogether.

The timing of the Australian export program is also an important consideration for ensuring market access for southern durum. With the export program typically focused on the first half of the marketing year, it is critical that sellers take this into consideration when making decisions about the timing of sales.

Holding durum later in the post-harvest period may result in a scenario where by there is no buyer appetite for the grain. For this reason, in most seasons holding

durum later in the post-harvest period should be considered a higher risk compared with holding other grades of wheat or commodities.

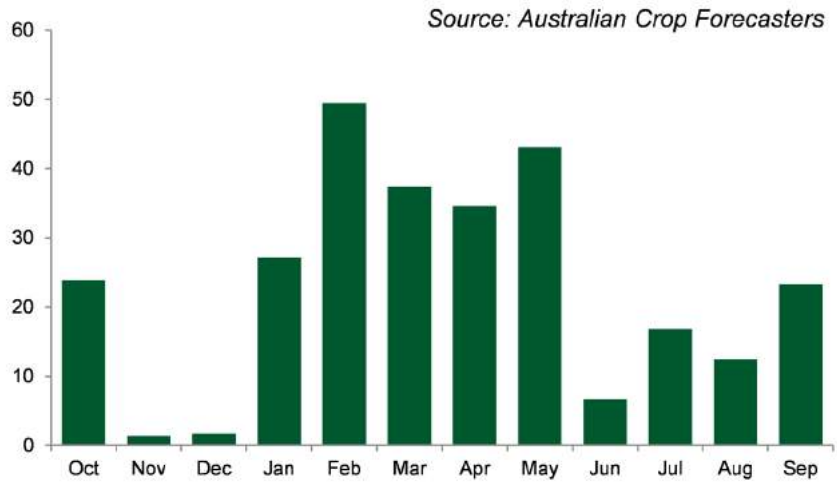
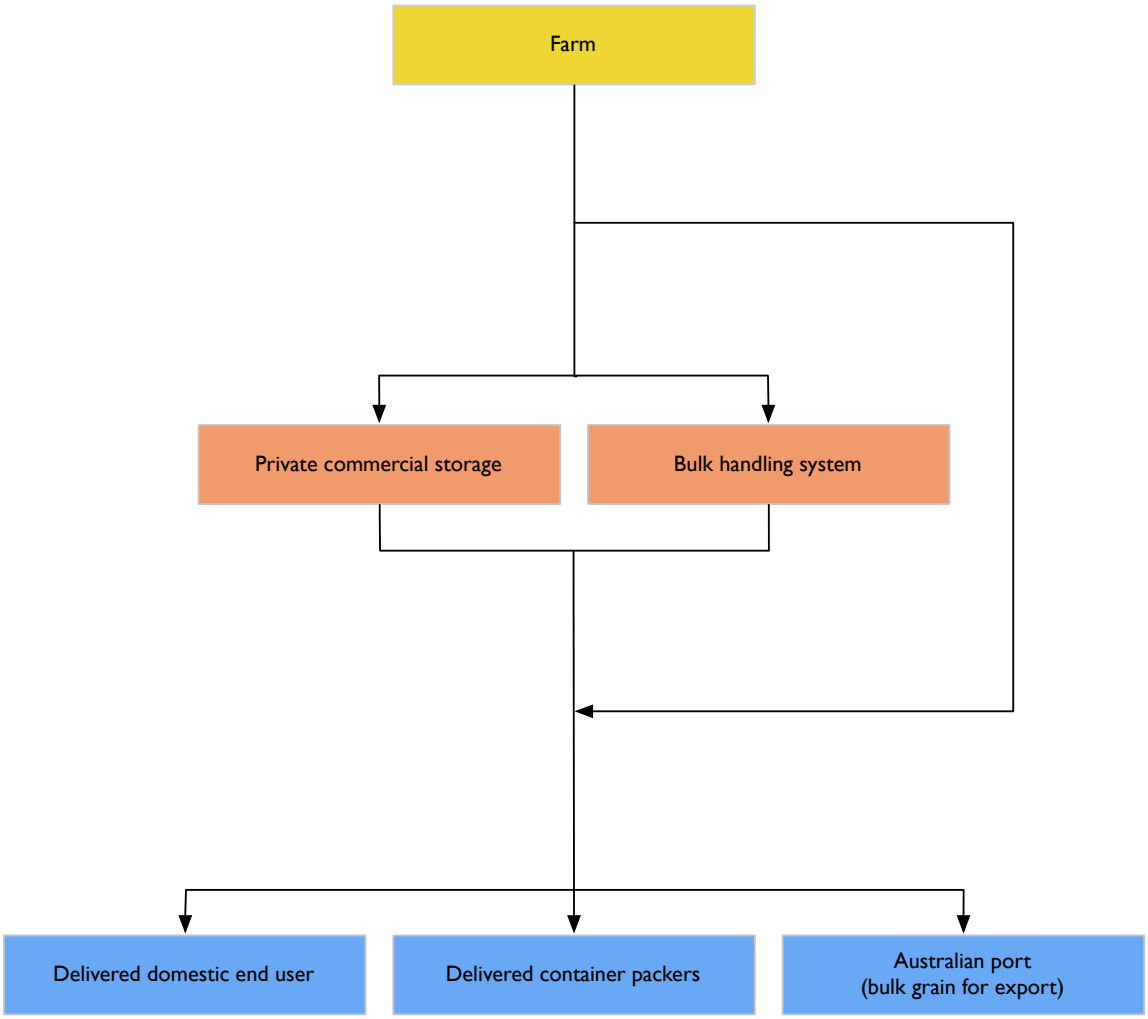


Figure 21: *Average monthly export pace for Australian durum over 10 years.*

Source: Australian Crop Forecasters



Note to figure:
Storage decisions should be determined by assessing market access. In Western Australia the large majority of wheat is exported in bulk. Hence the bulk handling system should provide efficiencies to market. Alternatively on-farm and private commercial storage may be a more reasonable method of accessing the container and end user markets.

Profarmer AUSTRALIA

Figure 22: *Australian supply-chain flow.*

Source: Profarmer Australia

15.2.3 Converting tonnes into cash for southern durum

Growers of durum have a number of avenues to convert tonnes of grain into cash.

In the forward market, an area program allows producers to commit to planting a certain area to durum and the buyer may take on some or all of the production risk. These contracts are normally offered directly by domestic users or by their agents. Area contracts can take a number of different forms so it is important when comparing these contracts that the seller considers the following risks in particular:

- Production risk–is the buyer taking on all of the production risk, or does the contract include minimum and/or maximum volume commitments?
- Quality risk–what premiums and discounts are being offered for protein, screenings and other quality parameters? Are quality discounts based on a sliding scale based on the quality produced, or set based on the bin grade delivered?

Forward durum multigrade contracts for fixed tonnages are also available. An important consideration of any forward contract is the quality that is deliverable against the contract. There are a large number of receival grades for durum from DR1 down to DRF, so it is important to consider which grade you may end up delivering and whether you are able to deliver the quality specified in your contract.

Pricing in the durum market is not always transparent, with few buyers and a number of transactions taking place outside the public indicative bid, so it can be difficult to gauge fair market value. In periods of short supply durum can trade above the indicative public bid. Hence placing a firm offer to the market above the public indicative bid can be an effective means of achieving fair value for your durum. Considering market conditions and prices from several previous years, e.g. the last decade, may help you decide on contract terms and the price you want to achieve (see Figure 23).

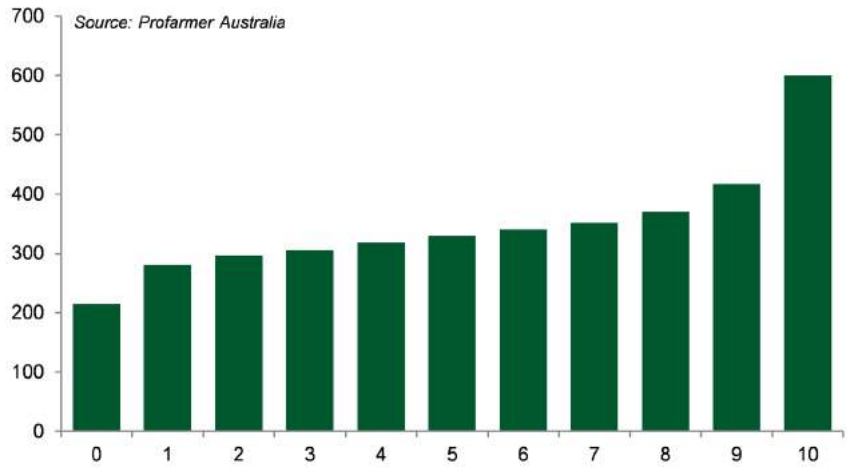


Figure 23: *Port Adelaide durum deciles. Deciles provide an indication of price performance relative to historical values. Decile 1 indicates values in the bottom 10% of historical observations, and a decile 9 indicates the top 10%. This chart is based on price observations from August 2009 to current.*

Source: Profarmer Australia

Current and past research

Project Summaries

As part of a continuous investment cycle each year the Grains Research and Development Corporation (GRDC) invests in several hundred research, development and extension and capacity building projects. To raise awareness of these investments the GRDC has made available summaries of these projects.

These project summaries have been compiled by GRDC's research partners with the aim of raising awareness of the research activities each project investment.

The GRDC's project summaries portfolio is dynamic: presenting information on current projects, projects that have concluded and new projects which have commenced. It is updated on a regular basis.

The search function allows project summaries to be searched by keywords, project title, project number, theme or by GRDC region (i.e. Northern, Southern or Western Region).

Where a project has been completed and a final report has been submitted and approved a link to a summary of the project's final report appears at the top of the page.

The link to Project Summaries is https://grdc.com.au/research/projects

Final Report Summaries

In the interests of raising awareness of GRDC's investments among growers, advisers and other stakeholders, the GRDC has available final reports summaries of projects.

These reports are written by GRDC research partners and are intended to communicate a useful summary as well as present findings of the research activities from each project investment.

The GRDC's project portfolio is dynamic with projects concluding on a regular basis.

In the final report summaries there is a search function that allows the summaries to be searched by keywords, project title, project number, theme or GRDC Regions. The advanced options also enables a report to be searched by recently added, most popular, map or just browse by agro-ecological zones.

The link to the Final Report Summaries is http://finalreports.grdc.com.au/final_reports.php

Online Farm Trials

The Online Farm Trials project brings national grains research data and information directly to the grower, agronomist, researcher and grain industry community through innovative online technology. Online Farm Trials is designed to provide growers with the information they need to improve the productivity and sustainability of their farming enterprises.

Using specifically developed research applications, users are able to search the Online Farm Trials database to find a wide range of individual trial reports, project summary reports and other relevant trial research documents produced and supplied by Online Farm Trials contributors.

The Online Farm Trials website collaborates closely with grower groups, regional farming networks, research organisations and industry to bring a wide range of crop research datasets and literature into a fully accessible and open online digital repository.

Individual trial reports can also be accessed in the trial project information via the Trial Explorer.

The link to the Online Farm Trials is http://www.farmtrials.com.au/

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