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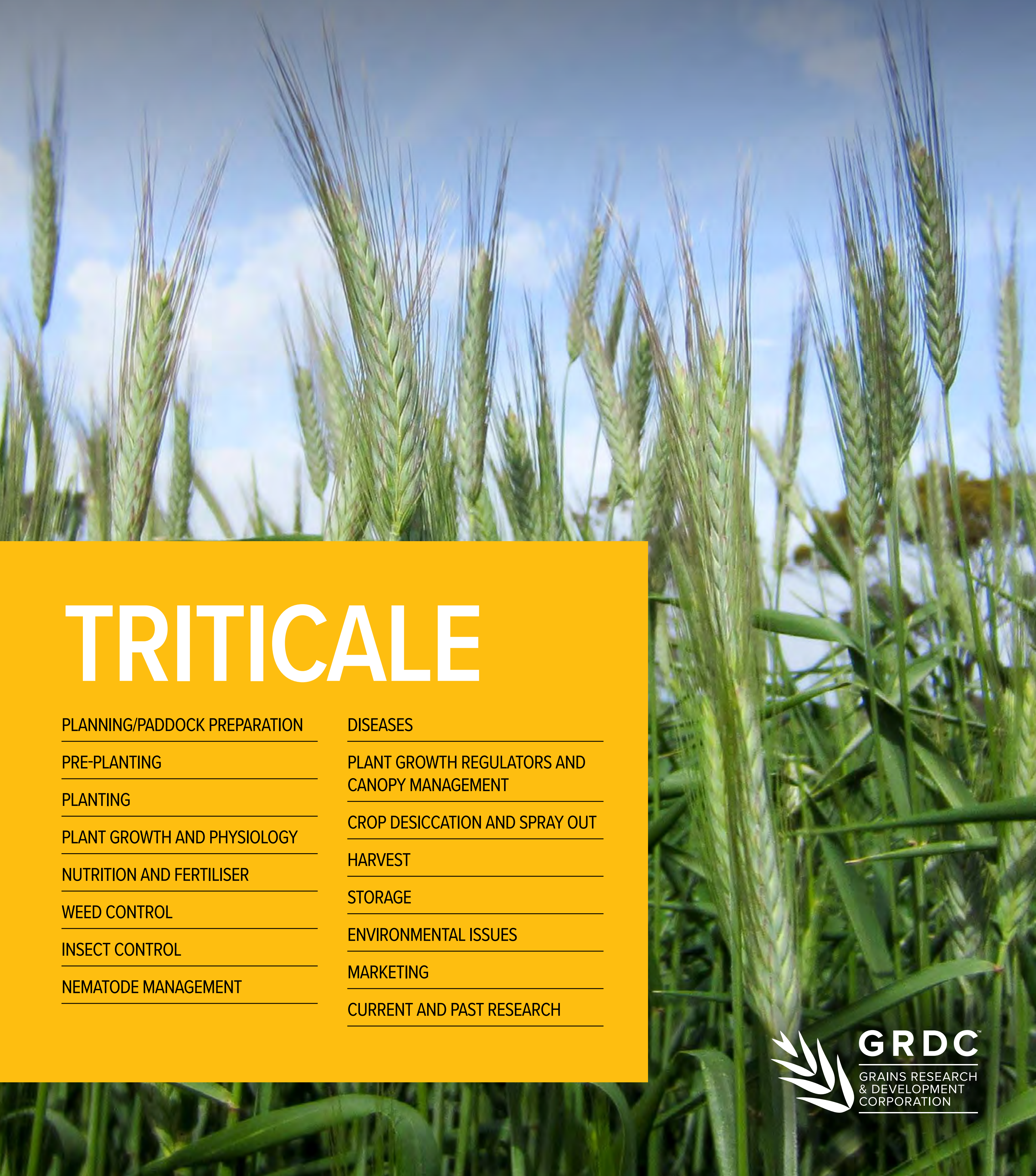

TRITICALE

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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5 Nutrition and fertiliser

Introduction

A.1 Crop overview

Triticale is an established small cereal crop which combines the productivity of wheat with the hardiness of rye. Triticale was developed by human intervention from crosses between wheat (genus *Triticum*) and rye (genus *Secale*). Its kernels are longer than wheat seeds and are plumper than rye. Its colour can range from the tan of wheat to the grey-brown colour of rye (Photo 1). Triticale has several advantages in Australian conditions; it is a relatively low input cereal crop with good disease resistance, particularly to rusts. It is as high a quality feed grain as wheat and is a hardy plant.

It makes good use of land that is marginal for other cereals. It has been developed to incorporate the high yield potential and quality of wheat and the adaptability of rye and is adapted to a wide range of soil types and environments. Triticale has an aggressive root system that binds light soils better than wheat, barley or oats. Under ideal conditions, researchers have found that triticale can out-yield wheat and barley and sometimes oats. It can out yield wheat in several situations: on acid soils, in cool high-rainfall areas, and on low-nutrient soils such as those with two levels of manganese and copper. Triticale is well established as an ingredient in livestock rations.

Photo 1: *Wheat (left), rye (middle) and triticale (right) grain. Note that triticale grain is significantly larger than wheat grain.*

Source: USDA

It is a tall crop bred for strong straw strength which can be useful in rocky paddocks or circumstances where crops have been known to lodge. Triticale can out-yield barley under good conditions, and its dual purpose use as grain or forage makes it a useful crop for mixed enterprise farms.

Triticale in Australia has a spring growth habit which means it behaves similarly to most cereal crops, maturing in late spring to early summer. Breeding and selection programs have ensured varieties possess a range of disease and pest characteristics which can compliment disease management for other cereals. It can also carry diseases which may affect other cereal species.

Triticale and wheat are similar crops, but triticale represents a valuable alternative to wheat due to its greater biomass production and grain yield in Mediterranean-type growing conditions, such as those in parts of southern Australia. [1]

Triticale can be less susceptible to the common fungal diseases of cereals which make it suitable for use in rotations where stubble is retained. Some varieties have

1 Bassu, S., Asseng, S., Giunta, F., & Motzo, R. (2013). Optimizing triticale sowing densities across the Mediterranean Basin. *Field Crops Research*, *144*, 167–178.

good resistance to stem, leaf and stripe rusts, mildew and Septoria tritici blotch as well as both resistance and tolerance to Cereal Cyst Nematode (CCN).

Triticale has poor tillering capacity and good tolerance to shattering. This makes triticale a useful cereal as a cover crop to establish undersown lucerne or medic, but seeding rates may need to be reduced. [2]

Besides its use as a feed grain, triticale can be used as a forage crop for ruminants and as a cover crop.

When added to a rotation, triticale may increase yields of other crops in the rotation, reduce costs, improve distribution of labour and equipment use, provide better cash flow, and reduce weather risk. Additionally, production of triticale may provide environmental benefits, such as erosion control and improved nutrient cycling. [3]

Triticale yields more than its ancestors in two types of marginal conditions; highlands where acid soils, phosphorus deficiency and foliar diseases are dominant, and in the arid and semi-arid zones where drought affects crops production. [4]

Observed traits suggested for the higher yields in triticale than wheat include greater early vigour, a longer spike formation phase with same duration to flowering, reduced tillering, increased remobilization of carbohydrates to the grain, early vigorous root growth and higher transpiration use efficiency. [5]

Triticale is a mainstream crop in Australia, mostly as spring types grown for grain production and also as longer-season, dual-purpose types grown for fodder use as hay, silage or grazing followed by grain production.

The grain is primarily used as stock feed, with a low level of triticale use in food products. Most of the grain is used domestically although small amounts are exported. [6]

Triticale usually commands a lower price per tonne at the farm gate. An exception to this can be where there is strong local demand for feed grain, where a better cash return with low transport costs could be expected. [7]

The market for triticale is small compared to other cereals as it must compete with barley as the preferred winter feed grain. To combat this, breeders have released improved and better adapted varieties that have good yield and grain quality characteristics, with many of the factors identified as the cause of inferior performance having been eliminated. [8]

MORE INFORMATION

A review of triticale uses and the effect of growth environment on grain quality

Triticale agronomy

A.1.1 Triticale for human consumption

Small amounts of triticale are marketed as niche products for human food consumption. Uses include as a flour supplement to wheaten flour for bread, biscuits and cakes, as rolled whole grains for breakfast cereals, triticale noodles and in the brewing and distilling industries (Photo 2). Triticale has a distinctive nutty, aromatic and naturally sweet flavour. [9] Triticale as a main cereal for bread making is constrained by variations in bread making quality, low and inferior gluten content and lower flour yield. Further, wheat and rye have already been established as the traditional bread cereals and hence consumers' preference to triticale may take some time to promote.

2 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

3 Gibson LR, Nance C, Karlen DL. (2005) Nitrogen management of winter triticale. Iowa University. http://farms.ag.iastate.edu/sites/default/files/NitrogenManagement.pdf

4 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

5 Bassu, S., Asseng, S., & Richards, R. (2011). Yield benefits of triticale traits for wheat under current and future climates. *Field Crops Research*, *124*(1), 14–24.

6 Cooper KV, Jessop RS, Darvey NL – Triticale in Australia – in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org. http://www.fao.org/docrep/009/y5553e/y5553e00.htm

7 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

8 Online farm trials. (2004). Triticale agronomy. http://www.farmtrials.com.au/trial/13801

9 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

Photo 2: *Wholegrain triticale flour (left) and kibbled triticale (right) milled for human consumption.*

Source: Blue Lake Milling

As consumers in general become more health conscious, they are becoming aware of the health benefits of including a range of cereal grains in their diets. This increased consumption of grains, together with the current consumer trend of trying new and novel products, is leading to an increase in consumer interest in seeking baked products, such as breads baked using cereal grains other than wheat. Thus, given the nutritional and agronomic advantages of triticale, the improvements taking place in terms of baking potential, as well as increasing level of consumer interest in products made from alternative grain cereals, triticale is believed to have the necessary attributes to become an important food cereal for humans in future. [10]

Main culinary uses of triticale:

- Triticale flour – can be used to make biscuits, rye-type crispbreads, cakes and muffins. The flavour and texture of breads made from triticale are similar to that of light rye bread.
- Triticale flakes – whole grain triticale is pressed and rolled, which than may be used like rolled oats to make a hot breakfast cereal or substituted for rolled oats in recipes (e.g. in cookies and muffins).

Nutrition credentials of whole grain triticale:

- Similar to wheat, with 13% protein, but lower in lysine and niacin.
- Lower in protein complex which forms gluten.
- A good source of phosphorus and magnesium and a very good source of manganese.
- Contains B-group vitamins, most notably thiamin and folate. [11]
- One study suggested that triticale could be a food source that reduced obesity and diabetes problems. [12]

MORE INFORMATION

Food uses of Triticale

A.1.2 Triticale for animal consumption

Triticale is a direct substitute for barley or wheat in animal feed rations. In pig and poultry diets triticale is equal to or better than wheat or maize in terms of energy value and superior in terms of protein content and quality. In dairy rations triticale has

10 McGoverin, C. M., Snyders, F., Muller, N., Botes, W., Fox, G., & Manley, M. (2011). A review of triticale uses and the effect of growth environment on grain quality. *Journal of the Science of Food and Agriculture*, *91*(7), 1155–1165.

11 Grain and legumes nutrition council. (2016). Triticale. http://www.glnc.org.au/grains/types-of-grains/triticale/

12 Cooper 1985 – in Tshewang S. (2011). Frost tolerance in Triticale and other winter cereals at flowering. https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

an advantage over barley due to its high metaboliseable energy, palatability and ease of milling. [13]

The major uses for triticale grain are as a feed supplement in the dairy industry, as a component ingredient in beef feedlots and as a constituent of compound rations for intensive livestock (pigs and poultry) rations. In livestock diets, triticale has a similar role to other cereals. Triticale is higher in energy than barley and has many desirable nutritional characteristics for all classes of livestock. It is primarily an energy source having moderate protein content with high starch and other carbohydrates, giving it high energy content.

Photo 3: *Triticale is often chosen by farmers for stock feed due it's high nutritional qualities.*

Source: The Australian Dairy Farmer

Triticale is a direct substitute for barley or wheat in animal feed rations. In pig and poultry diets triticale is equal to or better than wheat or maize in terms of energy value and superior in terms of protein content and quality (essential amino acid content and availability). In dairy rations triticale has an advantage over barley due to its high metabolisable energy, palatability and ease of milling. [14]

A key physical feature of triticale is that it is a soft grain with a hardness index almost half that observed for wheat and barley. This is an advantage as less mechanical energy is required to mill triticale compared to wheat and barley prior to inclusion in livestock diets.

On farm, triticale can be fed to livestock in the same way wheat or barley would be fed. [15]

Triticale growing regions correspond with the bulk of Australia's intensive livestock production, making triticale grain readily accessible by most feed mills.

There is a high demand for feed grain in the Wimmera region, especially for triticale from the dairy and pig industries. The reduced transport costs and the slightly higher price for triticale compared to other feed grains makes triticale an attractive proposition. [16]

MORE INFORMATION

Triticale: stock feed guide

A guide to the use of Triticale in livestock feeds

13 Online farm trials. (2004). Triticale agronomy. http://www.farmtrials.com.au/trial/13801

14 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

15 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

16 University of Sydney. (2012). Triticale.

MORE INFORMATION

Triticale offer benefits over wheat for biofuel

A.1.3 Triticale for biofuel

Alternative fuels are required owing to the impending shortage and soaring prices of fossil fuels, and increasing global concern about the welfare of the environment. Biofuels are produced from organic matter and are a possible alternative fuel. Modern cultivars of triticale are a competitive feedstock for ethanol production. Advantageously, triticale possesses an autoamylolytic enzyme system that aids in converting large quantities of starch into fermentable sugars. Triticale is better suited to the production of biofuel than wheat. The use of triticale for biofuels has been explored in Europe and could have potential elsewhere in the world.

A.2 Growing region

Australia's Western growing region comprises the cropping areas of Western Australia (WA), where soil fertility is generally low to very low, and yields depend on winter and spring rainfall.

In many areas, yields are low compared to global standards; this is compensated for by the large scale and degree of mechanisation of cropping enterprises. Due to long-term variability in seasonal rainfall, production is lower in the coastal areas of WA than in the Northern and Southern regions of WA.

Wheat, barley, canola and lupins are the dominant crops, with livestock enterprises in mixed farming systems often of less importance than in other regions of Australia. The Western Region has a relatively small population and feed industry, so the state is export-oriented, with 80–90% of annual grain production exported to more than 50 countries worldwide with Asia and the Middle East our largest markets.

The grains industry is the largest agricultural sector in Western Australia delivering around $4.2 billion to the state economy each year – with the majority of this coming from cereal production ($3.3 billion) and contributions from oilseeds ($0.7 billion) and legumes ($0.15 billion).

WA produces about 10 million tonnes of grain each year from around 4000 rain-fed farms ranging in size from 1000 to 15 000 hectares.

The state's grain production area, known as the 'wheatbelt', covers seven million hectares across the south-west corner of the state. [17]

The climate in south-western Australia is Mediterranean, with hot dry summers and agriculture relying heavily on winter rain. Dryland cereal cropping, mixed with sheep and beef farming is predominant in the northern, central, great southern and south eastern agricultural regions. Higher winter rainfall and sufficient ground water supplies in the South-West region allows irrigation of pastures for dairy and beef, fruit, and vineyards for both table and wine grapes. Forestry has also been a major industry in the past. [18]

A.3 Brief history

The first wheat/rye cross-breeding occurred in Scotland in 1875, but this crossing was sterile; in 1888, German botanists first discovered how to produce a fertile hybrid of the two grains. The name triticale first seems to have been used in Germany about 1935. [19]

In the 1950s, plant geneticists hoped that a cross fertilisation of wheat and rye would produce a cereal with superior yield. The hardiness and disease resistance of rye was combined with the milling and baking qualities of wheat.

17 DAFWA. (2016). Western Australian Grains Industry. https://www.agric.wa.gov.au/grains-research-development/western-australian-grains-industry

18 Soilquality.org (2016). Western Australia. http://www.soilquality.org.au/au/wa

19 Whole grains council. Rye + Triticale August grains of the month. http://wholegrainscouncil.org/whole-grains-101/easy-ways-enjoy-whole-grains/grain-month-calendar/rye-triticale-august-grains-month

In 1970, the first commercial variety of triticale went on sale and triticale bread, flour and breakfast cereals became available. Triticale was hyped as a miracle crop during this time, but initial interest faded when crops were inconsistent and acceptance was slow. As such, triticale has not achieved its objectives to dominate as a grain for food production. Today in Australia triticale is found in a range of grain foods. [20]

A.3.1 Triticale in Australia

Triticale was introduced into Australia in the early 1970s as experimental lines for evaluation. Breeding and selection programs were initiated at several universities and state government departments of agriculture, and a number of varieties were released, which were mostly spring-grain lines introduced from CIMMYT. Triticale was quickly taken up as a useful crop for grain and fodder production on acid and waterlogged soils and for producing an economic and soil-conserving crop on lower rainfall, nutrient-impoverished soils. Initially, triticale was mostly used on-farm or traded locally as stock feed. It was often sought as a more easily-traded feed grain than wheat, which had to be marketed through the Australian Wheat Board. On the other hand, as triticale was not a well-known grain, and as the quantity available was limited, in some areas triticale could prove difficult to sell for a good price, which tended to limit its adoption.

The first Australian cultivar was Growquick, a later- maturing line of poor-grain type most suitable for grazing use. By the mid-1980s, 11 grain cultivars had been released.

In the early 1980s, wheat stem rust races evolved in Queensland, which were virulent on these cultivars. In order to reduce the likelihood of rust epidemics and further evolution of virulent races, the rust-susceptible cultivars were no longer recommended, and breeders sought to produce cultivars with full rust resistance. Once this was achieved, an increasing amount of triticale was produced and after many years of good results, users gained confidence in this grain, driving an increasing demand for triticale and improved prices (Figure 4 and Table 1). [21]

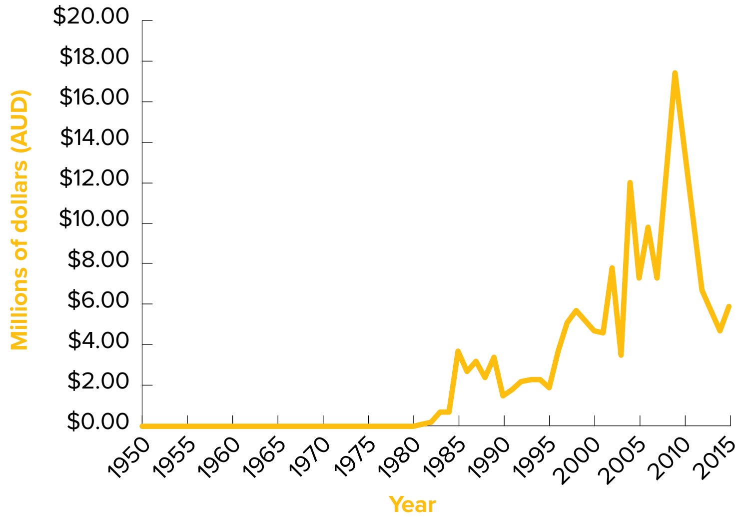

Figure 1: *Gross Value production of Triticale in Western Australia.*

Source: AgData

20 Grain and legumes nutrition council. (2016). Triticale. http://www.glnc.org.au/grains/types-of-grains/triticale/

21 Cooper KV, Jessop RS, Darvey NL in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org. http://www.fao.org/docrep/009/y5553e/y5553e00.htm

Table 1: *Triticale production in Australia ('000 tonnes).*

Year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
Production	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Year	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**
Production	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Year	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
Production	0	0	0	0	0	6	13	36	21	28	23	25	11	15
Year	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Production	17	18	22	12	20	35	35	43	35	30	40	23	73	47
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**				
Production	60	36	na*	70	na*	19	36	12	17	22				

Source: Australia Bureau of Statistics. * Data not collected for 2008 and 2010

Planning/Paddock preparation

Key messages

- Triticale is suited to all soil types but has a significant yield advantage over wheat and barley when grown in a number of problem soil situations.
- Of all the cereals available to farmers, triticale has the best adaptation to waterlogged soils and those of high pH (alkaline soils).
- Triticale is also tolerant of low pH (acid soils), grows well on sodic soils and tolerates soils high in boron.
- Triticale can out-produce other winter cereals on lighter, lower fertility soils. It has more vigorous root system than wheat, barley or oats binding light soils and extracting more nutrients from the soil.
- Incorporate crop rotation in farming systems – triticale can provide valuable benefits to a sequence.
- Ensure that paddocks are weed free before planting seed.
- Test soils for disease and nematodes and sample paddock soil for insects.

1.1 Paddock selection

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]

1.1.1 Topography

Topographical characteristics can determine crop and pasture options. Crops and varieties prone to lodging should be avoided in uneven paddocks. Waterlogged conditions also reduce root growth and can predispose the plant to root rots. Triticale is less prone to waterlogging than other cereals so can be a good option for areas where water may sit. The topographic variations typical of large agricultural paddocks can have a substantial impact on dynamics of soil mineral nitrogen (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 cover crop management. Management decisions regarding where to plant crops can vary depending on the management goals and complexity of the terrain. For example, cover crops seem to be particularly advantageous on eroded unfertile slopes where legumes bring the needed N inputs, and all cover crops contribute to erosion control and Carbon sequestration. [2]

1.1.2 Soil

Soil characteristics (surface and subsurface) such as soil pH, sodicity, salinity, acidity, texture, drainage characteristics and compaction will affect variety selection.

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

2 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.

Of all the cereals available to farmers, triticale has the best adaptation to waterlogged soils and those of high pH (alkaline soils). Triticale is also tolerant of low pH (acid soils), grows well on sodic soils and tolerates soils high in boron. In nutrient deficient soils, triticale appears to respond better to applied fertilisers than other cereals. Triticale has the capacity to survive utilising trace elements in soils which would be considered nutrient deficient for any other type of crop. [3]

Triticale is suited to all soil types but has a significant yield advantage over wheat and barley when grown in a number of problem soil situations including:

- Acidic soils (pH less than 4.5 $CaCl_2$) which are high in aluminium (greater than 10% of the total cations) e.g. WA, southern NSW and north east Vic.
- Alkaline soils
- Waterlogged conditions. [4]

NVT experiments on alkaline soil in southern Australia, have indicated good yields compared with other cereals, even in dry years. Farmer experience on dry rocky soils in southern Australia has shown a 25% yield advantage for triticale, compared with wheat. In these difficult conditions, the variety Rufus has proved most valuable. [5]

Triticale will grow on similar soils to wheat and barley, but is also adapted to soils that are too acid for the other cereals. It is relatively boron tolerant and is tolerant to high aluminium soils. On alkaline soils where other cereals are affected by manganese, zinc or copper deficiency triticale is less affected.

Triticale can out-produce other winter cereals on lighter, lower fertility soils. It has more vigorous root system than wheat, barley or oats binding light soils and extracting more nutrients from the soil. [6]

Triticale and wheat are similar crops, but triticale represents a valuable alternative to wheat due to its greater biomass production and grain yield in Mediterranean-type growing conditions, such as those in parts of western Australia. [7]

IN FOCUS

The impact of different soil moisture and soil compaction on the growth of triticale root system

Effects of different soil moisture (soil drought and waterlogging) and soil compaction (1.33 and 1.50 g·cm−3) on the growth and morphological traits of the root system were studied in four breeding forms and seven cultivars of triticale. Morphological changes, including the restriction of root extension, expansion and proliferation of laterals roots, occur in plants grown in different soil moisture and in compact soil. Results have demonstrated a relatively broad variation in the habit of the triticale root system. Plants grown under compact soil and low or high soil water content showed a smaller number and less dry matter of lateral branching than plants grown in control conditions. The harmful effects of compact soil and drought conditions on the growth of roots was greater when compared with that of plants exposed to waterlogging. The observed effects of all treatments were more distinct in a drought sensitive strains. The drought resistant forms were more characterized with extensive rooting and by smaller alterations in the root morphology under the stress conditions compared with drought sensitive one (Photo 1). Results confirm that the

3 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

4 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

5 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

6 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

7 Bassu, S., Asseng, S., Giunta, F., & Motzo, R. (2013). Optimizing triticale sowing densities across the Mediterranean Basin. *Field Crops Research*, *144*, 167–178.

breeding forms (CHD-12 and CHD-173) of a high drought susceptibility was found to be also more sensitive to periodical soil water excess. A more efficient water use and a lower shoot to root (S/R) ratio were found to be major reasons for a higher stress resistance of the breeding forms (CHD-220 and CHD-247). The reasons for a different response of the examined breeding forms and cultivars to the conditions of drought or waterlogging may be a more economical water balance and more favourable relations between the shoot and root dimensions in the drought resistant forms and cultivars. [8]

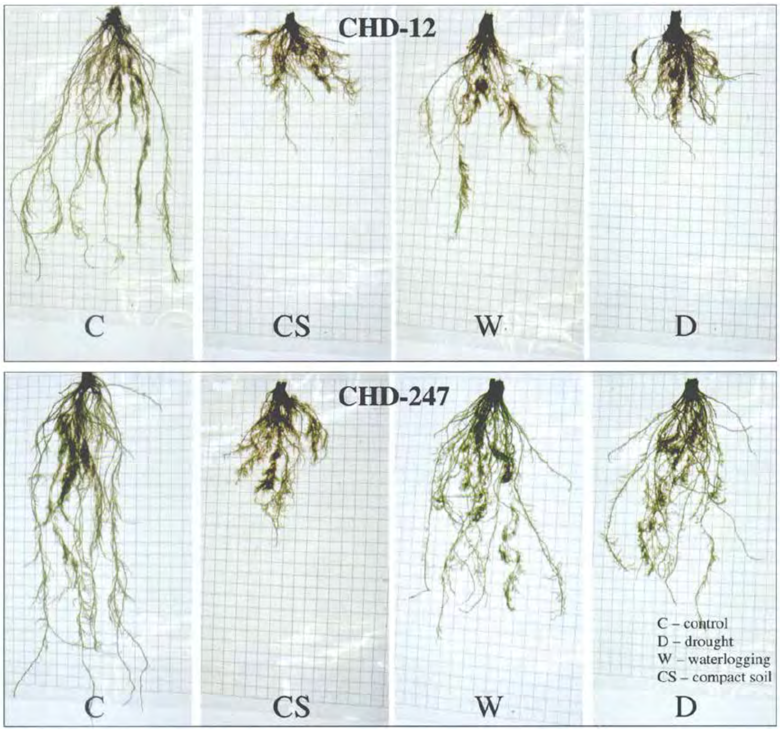

Photo 1: *Effects of compact soil (CS), waterlogging (W) and soil drought (D) on root growth of drought resistant (CHD-247) and drought sensitive (CHD-12) 3-weeks old triticale seedlings.*

Soil compaction has been found to limit triticale growth. Severe soil compaction treatments decreased leaf number, leaf area and dry matter of shoots and roots, while increasing shoot-to-root dry matter ratio. In addition, high level of soil compaction strongly affected the length of seminal and seminal adventitious roots, and the number and length of lateral roots developed on the seminal root. Severely compacted soil also negatively impacts photosynthesis, gas exchange, transpiration rate and stomatal conductance. [9]

Soil pH

Key points:

- Triticale can grow on acidic soils (pH less than 4.5 $CaCl_2$) and alkaline soils
- Soil pH is a measure of the concentration of hydrogen ions in the soil solution.

8 Grzesiak, S., Grzesiak, M. T., Filek, W., Hura, T., & Stabryła, J. (2002). The impact of different soil moisture and soil compaction on the growth of triticale root system. *Acta Physiologiae Plantarum*, *24*(3), 331–342.

9 Grzesiak, M. T. (2009). Impact of soil compaction on root architecture, leaf water status, gas exchange and growth of maize and triticale seedlings. *Plant Root*, *3*, 10–16.

- 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.
- Soil acidity is a major constraint to farming in Western Australia.

As a general rule, Triticale's are suited to all soil types, but typically have a yield advantage over wheat and Barley on light acidic soils higher in exchangeable Aluminium. In these acidic soils higher in Aluminium, Canobolas⦇D⦈ and Bogong⦇D⦈ would be the two most preferred varieties of choice. [10]

In 2011, a trial tested triticale growth in soils with low subsoil pH and aluminium toxicity on a property east of Perenjori, WA. After being attacked by cutworm 4 weeks after sowing the triticale regenerated quickly. The newer varieties, Berkshire⦇D⦈ and Speedee, yielded higher than the Tahara (Table 1). [11]

Table 1: *Yield and quality of triticale varieties grown on low subsoil pH and aluminium toxicity soils in WA.*

Variety	Yield (t/ha)	Protein (%)
Berkshire⦇D⦈	1.14	11.5
Speedee	0.94	11.8
Tahara	0.77	11.8

Source: Liebe Group, 2011

Another earlier trial in WA investigated the benefits of soil amendments on acid soil for triticale and wheat. There was a significant yield improvement of Tahara triticale when gypsum was applied to the surface to treat subsurface acidity. Wheat did not show the same response. Whilst the variety Wyalkatchem does have good tolerance to aluminium, triticale is highly tolerant, and would be expected to be the least likely to respond to changes in levels of toxic aluminium in the subsoil. The liming sources of lime sand and dolomite had no effect on yield of either the triticale or wheat in the first year of application. Due to their solubility the effects of these liming sources may be seen in the next few years. [12]

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).

10 Viterra. Bongong and Canobolas⦇D⦈ Triticale – SA/Vic/NSW seed factsheet. http://www.hartbrosseeds.com.au/f.ashx/Bogong⦇D⦈-Canobolas⦇D⦈-Factsheet.pdf

11 Johnston C. (2011). Triticale variety demonstration. Liebe Group. http://www.farmtrials.com.au/trial/10587

12 Conley T, Mureschi L. (2003). Soil amendments. Liebe Group and CSBP. http://www.farmtrials.com.au/trial/10324

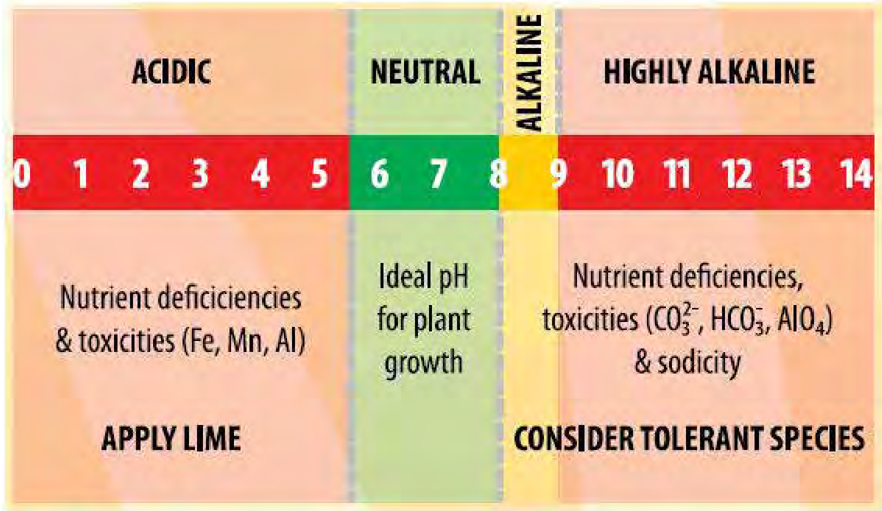

Figure 1: *Classification of soils on the basis of pH (1:5 soil:water), the implications for plant growth and some management options.*

Source: Soilquality.org. 13

Subsurface acidity is a major constraint to crop and pasture productivity right across WA's grain belt, estimated to reduce crop yields by 9–12%.

More than 70% of surface soils and almost half of subsurface soils across WA's south-west are below appropriate pH levels for agricultural production (Figure 2).

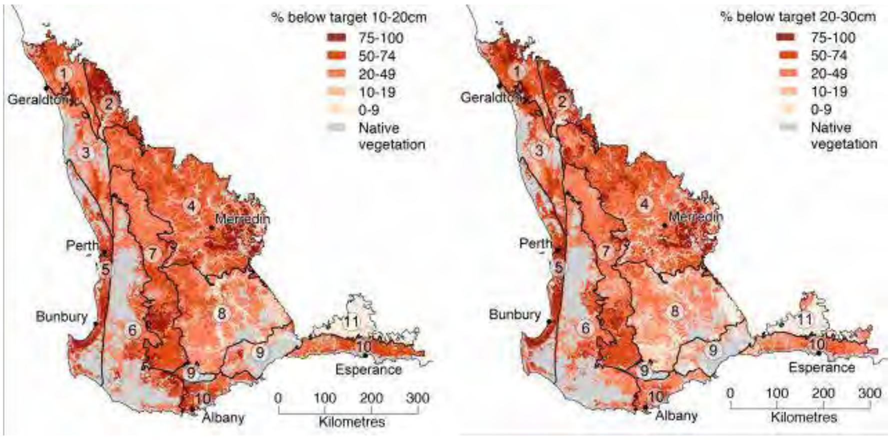

Figure 2: *Percentage of sites sampled (2005–12) with soil pH at 10–20 cm depth (left) and 20–30 cm (right) below the DAFWA target of pHCa 4.8.*

Source: Gazey et al. 2013 in DAFWA

Some trace elements become more soluble at lower pH, as does aluminium (Al), which is toxic to plants when in solution. If soil pH is too low – below about 4.8 – the concentration of Al in the soil water increases rapidly and reduces root growth. The resultant smaller root systems have limited access to nutrients and water, leading to lower plant biomass and grain yields.

Adding lime to the soil raises the pH. Above pH 4.8 the Al becomes non-toxic in the soil, enabling the plants to develop effective root systems. Research shows that as well as improving crop yields and widening rotation options, liming has a long-term positive impact on the ecosystem by potentially boosting soil microbial activity, improving availability of major plant nutrients and helping to reduce weed seed banks.

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

MORE INFORMATION

Soil acidity in Western Australia

VIDEOS

WATCH: GCTV8: Liming Acids Soils.

PODCAST

LISTEN: Ground Cover Radio 109 Crop roots push deeper after lime.

DAFWA's recommended minimum pH levels for WA's agricultural soils to maintain or achieve yield potential (measured in pH calcium chloride– or pHCa) are:

- Surface (0–10 cm) pHCa 5.5
- Subsurface (10–20 cm and 20–30 cm) pHCa 4.8, and no less than pHCa 4.5 to avoid Al toxicity.

Yields should not be constrained by acidity when these levels are met.

Lime use is most effective if it is precisely targeted to property areas based on subsurface soil testing during the summer months to a depth of at least 30 cm (in 10 cm increments), and to 40 or 50 cm on sandy soil. Scheduled liming applications are required to maintain the desired pH level in the soil, with priority given to the farm's most productive cropping areas.

It is important that growers source the best value for money lime based on neutralising value (i.e. the carbonate content of lime determines the capacity of the lime to neutralise acidity) and particle size (i.e. the size of the lime particles determines how quickly the lime can neutralise acid). Lime with a high proportion of finer particles has a larger surface area to react with the acid in the soil.

Mechanically incorporating lime into the subsurface during amelioration with deep tillage, spading or mouldboard ploughing generally achieves more rapid improvements in subsurface pH levels. Variable rate technology can also be successfully applied to lime spreading. [14]

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. [15]

1.1.3 Sampling soil quality

Key Points:

- The approach taken will be defined by the purpose of the investigation, variability in the area sampled, and the analysis and accuracy required.
- For many soil quality parameters sampling is typically done to 10 cm, although 30 cm is required for carbon accounting purposes, stratification below 10 cm is recommended (e.g. 10–20, 20–30 cm).
- The sampling strategy should either integrate or describe the variation within the sampling area.
- Samples should be air dried or kept below 4°C prior to analysis. For biological measurements it is best to analyse as soon as possible.

Before you can decide how you are going to soil sample you need to be clear about the purpose of your sampling. Different sampling approaches may be required depending on what you are sampling for, the soil type, the management unit (e.g. paddock), soil spatial variability (changes in soil type, dunes-swales etc), the accuracy required of the result, and the value given to the information provided (Photo 2). So before you start, define very clearly the question you are asking of your soil samples. Consult a professional soil scientist, agronomist or your analytical laboratory to be sure that your soil samples are taken at the right time, from the right depth, the

14 GRDC. (2016). Soil acidity in WA. GRDC Hot Topics. https://www.agric.wa.gov.au/soil-acidity/soil-acidity-western-australia

15 Soilquality.org. Soil pH – South Australia. http://www.soilquality.org.au/factsheets/soil-ph-south-austral

right place, in the appropriate number, and are stored in such way that the analysis required is not compromised. If quantitative soil analyses (kg/ha) are required then soil bulk density must also be measured and this requires considerable care.

Photo 2: *To be meaningful, soil sampling needs to take into account spatial variation in the soil condition. Differences in soil type, nutrient status and other soil properties may be exhibited within a paddock.*

Source: Soilquality.org

Sampling strategy

Soil properties and fertility often vary considerably, even over short distances, necessitating a sampling strategy which either integrates this variation through creating a composite sample (sampling across) or describes it through including replicate samples (sampling within). Describing the variation requires a defined sampling within each different soil patch and analysing replicate samples separately. Such an approach might be required where there are consistent zones within a field such as under controlled traffic systems, perennial row or tree crops or raised bed systems. More often, the variation within the field is integrated into a single sample through creating a composite. Examples of these are illustrated in Figure 3. 'A' is a random sampling that integrates the variation across the field, but samples are strategically located such that the location of samples approximates the relative representation of the different soil types. Sampling type 'B' uses a transect method to integrate the variation across the field, and in 'C' equal numbers of samples are taken from each zone and the area samples kept separate to obtain different soil analyses for each zone.

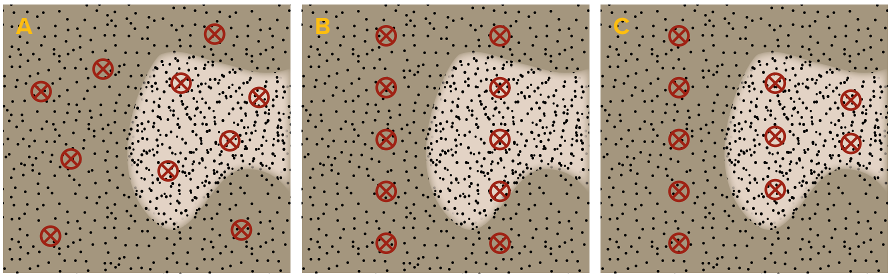

Figure 3: *Sampling strategies used to create a composite sample that integrates variation across different soil types (A & B) and a strategy to describe variation by sampling zones and analysing samples separately ©. A: haphazard samples strategically located to approximate the relative representation of different soil types. B: samples taken along transects intersecting different soil types. C: equal numbers of samples from each zone.*

Source: Soilquality.org

Sampling equipment

Manual sampling is often used where sampling is only required to 10 cm and bulk density is not required. Small pogo type samplers enable quick sampling for qualitative determinations such as nutrient concentrations or disease presence. Ensure that your sampling equipment is cleaned before you start to avoid contamination. For deeper depths mechanical (hydraulic) samplers are usually required for most soil types. If using these for soil carbon sampling be careful not to contaminate samples with lubricating oil.

Sampling depth

Sampling for soil fertility or biological activity assessment is typically done to 10 cm depth as this is where most of the organic matter and nutrient cycling occurs. However, for mobile nutrients like nitrate or potassium, deeper sampling may be required on the more sandy soils. Sampling to the rooting depth of a crop of interest might be useful for these nutrients or when studying water availability, otherwise it is generally too onerous. When assessing soil carbon stocks for accounting or budgeting purposes, a sampling depth of 30 cm is required to conform with standard accounting procedures. When sampling below 10 cm, soil samples are usually stratified by depth increments (e.g. 10, 20, 30 cm), depending on the objectives. When characterising a soil for the first time, sampling corresponding to the different soil layer depths (horizons) is often useful. Plant litter on the soil surface is not usually included in soil samples while plant root material is usually included, although generally sieved out prior to analysis.

Sample handling

Samples can be stored in polythene bags but should generally be dried or kept cool prior to analysis. Air drying (< 40°C) is usually sufficient and storage below 4°C usually arrests most biological activity. Dried samples can be broken up if clods are present, and any stones removed. If the amount of material collected is too great to manage and ship then it can be reduced in size by careful quartering, ensuring that there is no discrimination against particular particle sizes. Samples are typically put through a 2 mm sieve prior to analysis. [16]

1.1.4 Paddock selection for forage cereals

Selecting a paddock for forage cereal production will depend on how the forage cereal will be used on the dairy farm. If the forage cereal is to provide additional grazing, then a well drained paddock that can resist pugging damage from dairy cows should be chosen. A paddock that has higher fertility and is well drained should be chosen to provide maximum dry matter production.

16 Soilquality.org. Soil sampling for soil quality – South Australia. http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia

It is best to select a paddock that has a low level of pasture grasses to avoid the risk of cereal disease transmission. Annual pasture grasses can be hosts for such diseases as Take-all, Rhizoctonia, Fusarium and Pythium. In traditional cereal growing areas, pasture grasses can be removed from the paddock in the year prior to cereal establishment by using herbicides to 'winter clean' the pasture or by green manuring to prepare the seed-bed.

Tough grasses such as bent grass, couches and kikuyu must be satisfactorily controlled before autumn sowing of cereals. These grasses will compete with the cereal for nutrients and moisture, both in autumn at establishment and in the following spring. [17]

1.1.5 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 cereals in the first year of rotation should for instance have a vigilant strategy for the control and prevention of seed set of key broadleaf weeds prior to a rotation to canola or legume crops.

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

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

For more information, see Section 6: Weed Control.

1.1.6 Fallow moisture and management

Paddocks with well-managed fallow periods significantly lower the risk of poor crop and financial performance. A growing crop has two sources of water: the water stored in the soil during the fallow, and the water that falls as rain while the crop is growing. Growers have some control over the stored soil water; measure soil water before planting the crop. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when needed. Timely weed control can reduce moisture and nutrition loss, prevent an increase in the seedbank, and decrease the risk of disease carryover. Absence (or restriction) of grazing periods maintains soil friability and groundcover. Prolonged grazing periods may create crop emergence problems through induced surface compaction. [18]

1.2 Paddock rotation and history

Paddock choice can determine the amount of disease, weed and nutrient pressure on the crop. Increasing interest in crop sequencing is providing more financial and agronomic data to help growers to choose crops and paddocks each year. Crop rotation is a key strategy for managing Australian farming systems, and improvements in legume and oilseed varieties and their management have facilitated this shift. Leading growers and advisers advocate sustainable crop sequences as a valuable strategy for southern farming systems. Many growers are sacrificing cereal yield and protein by not adopting current research findings on the use of correct sequences. In many of Australia's grain-growing regions, broadleaf crop options have been seen as riskier and less profitable than cereals. This perception has been driven, in part,

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17 Agriculture Victoria. (2008). Establishing forage cereals.

18 N Border, K Hertel, P Barker (2007) Paddock selection after drought. NSW Department of Primary Industries, February 2007.

by fluctuating prices and input costs associated with the broadleaf crop in the year of production, and difficulties in marketing. However, when the profitability of the entire rotation is assessed, it is often more profitable to include broadleaf crops in the crop sequence. [19]

1.2.1 Triticale as rotation crop

Besides its use as a feed grain, triticale can be used as a forage crop for ruminants and as a cover crop.

When added to a rotation, triticale may increase yields of other crops in the rotation, reduce costs, improve distribution of labour and equipment use, provide better cash flow, and reduce weather risk. Additionally, production of triticale may provide environmental benefits, such as erosion control and improved nutrient cycling. [20]

Triticale yields more than its ancestors in two types of marginal conditions; highlands where acid soils, phosphorus deficiency and foliar diseases are dominant, and in the arid and semi-arid zones where drought affects crops production. [21]

Observed traits suggested for the higher yields in triticale than wheat include greater early vigour, a longer spike formation phase with same duration to flowering, reduced tillering, increased remobilisation of carbohydrates to the grain, early vigorous root growth and higher transpiration use efficiency. [22]

Trials in the UK suggest that triticale gives a greater yield advantage than wheat in the second cereal position in a rotation. The main reason for this difference was thought to be triticale's better resistance to take-all. [23]

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

20 Gibson LR, Nance C, Karlen DL. (2005) Nitrogen management of winter triticale. Iowa University. http://farms.ag.iastate.edu/sites/default/files/NitrogenManagement.pdf

21 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

22 Bassu, S., Asseng, S., & Richards, R. (2011). Yield benefits of triticale traits for wheat under current and future climates. *Field Crops Research*, *124*(1), 14–24.

23 Clarke S, Roques S, Weightman R, Kindred D. (2016). Understanding Triticale. https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf

Table 2: *Advantages and disadvantages of including triticale in crop rotations.*

Advantages	Disadvantages
Triticale is a relatively low input cereal crop with good disease resistance, particularly to rusts. It is as high a quality feed grain as wheat and is a hardy plant. It is a tall crop bred for strong straw strength which can be useful in rocky paddocks or circumstances where crops have been known to lodge. Triticale is more durable than wheat when grazed; which means it will be healthier and stand up to weeds, diseases and cold weather better than wheat. Many growers use triticale as a disease break in their rotations and value the benefits of triticale for its contribution to soil conservation. Thus, triticale assists in maintaining soil health by the reduction of nematodes, such as *Pratylenchus neglectus* and *thornei* (root lesion nematodes) and *Heterodera avenae* (cereal cyst nematode), and a range of fungi and bacteria that build up in the soil, reducing yields when the same crop species is grown repeatedly. Other favoured characteristics of triticale are its resistances to barley yellow dwarf virus, mildew and rusts, which may cause significant yield reductions in wheat, barley and oats. The extensive root system of triticale binds sandy soils, and the fibrous stubble reduces wind and water erosion. [24] Roots of triticale in nematode infested soil have been found to contain fewer nematodes than other cereals. Triticale is thus a useful rotational crop for areas infested with the root lesion nematode. [25]	One of the drawbacks of triticale grown for grain is that it is prone shattering. There is a spot about a quarter to a third of the way down from the tip on the rachis that is very weak. [26] Stripe rust may be a problem in triticale and there are now options to treat seed to provide seedling protection against stripe rust. Triticale grain is softer than wheat and barley grain. Soft grain is more prone to attack from weevils and other grain storage insects. [27] It can be difficult to find a market for triticale.

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 no longer a common practice because of the rising incidence of:

- difficult-to-control and herbicide-resistant weeds, particularly grass weeds
- disease build-up, e.g. crown rot, tan (yellow) spot, nematodes
- nitrogen (N) depletion and declining soil fertility

1.2.2 Break cropping

Farmers use their soil intensively. There are pressures to grow more and more crop - in volume or value - to maintain profits. Despite this, it is still important to grow cover crops. Cover or "break" crops include grasses such as triticale, rye and oats, and legumes such as cowpeas and vetch. They may be ploughed in and are called

24 Cooper KV, Jessop RS, Darvey NL in Mergoum, M., & Macpherson, H. G. (2004). Triticale improvement and production (No. 179). Food & Agriculture Org. http://www.fao.org/docrep/009/y5553e/y5553e00.htm

25 Vanstone, V., Farsi, M., Rathjen, T., & Cooper, K. (1996). Resistance of triticale to root lesion nematode in South Australia. In Triticale: Today and Tomorrow (pp. 557-560). Springer Netherlands.

26 Alternative crops – Triticale in the US.

27 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

"green manure" crops. These crops may also be mulched, slashed or sprayed, then later turned into the soil (incorporated).

For more information, see Section 2: Pre-planting.

Although cover crops do not normally produce income, they are important because they protect the soil and give other benefits (Table 3). Bare soil is easily damaged, it is best to protect it by maintaining plant cover. [28]

Much of the practice being adopted on farm in Australia involves the use of crops that can provide green manure benefits, but in most cases they host and multiply nematodes, and there is little information about their impacts on other soil borne fungi. [29]

Table 3: *Advantages and disadvantages of including cover crops in growing rotations.*

Advantages of cover cropping	Disadvantages of cover cropping
Protect the soil: much less erosion - soil washing away - and less surface crusting. Maintain fertility: by maintaining organic matter levels in the soil and, if a legume, adding nitrogen. Weed control: a healthy cover crop keeps a paddock free of weeds. Disease control: can provide a "break crop" that helps reduce disease, nematode, and perhaps pest, levels. For vegetable production, grasses rather than legumes tend to be best for this benefit. Biological tillage: less cultivation is needed because cover crops loosen the soil. Improved paddock access: cover crops can dry out a soil underneath and help farm operations to be timely. This drying out also makes nitrogen in the soil more available.	**Loss of land for cash crops**. If it is necessary to avoid this, do not grow the cover crops to maturity and grow only occasionally. A cover crop only once every two years still provides worthwhile benefits. On the other hand, once a year is better. **Cost of seed and sowing:** these costs are unavoidable but small. The costs associated with growing, such as watering, are usually avoidable. **Can become a weed**: usually not a problem in vegetable production. **Bulky crops**: can temporarily tie-up nitrogen and perhaps increase disease and have other effects. Their trash can also get in the way. If nitrogen deficiency in the following crop may be a problem, incorporate the cover crop earlier - for example 4–6 weeks before planting - or apply a nitrogen fertiliser to speed-up breakdown of the cover crop

Source: DPI NSW

VIDEOS

WATCH: The importance of Crop rotation.

1.2.3 Long fallow disorder

Soils naturally contain beneficial fungi that help the crop to access nutrients such as phosphorus (P) and zinc (Zn). The combination of the fungus and crop root is known as arbuscular mycorrhiza(e) (AM). Many different species of fungi can have this association with the roots of crops. Many that are associated with crops also form structures called vesicles in the roots. The severe reduction or lack of AM shows up as long fallow disorder—the failure of crops to thrive despite adequate moisture. Ongoing drought in the 1990s and beyond has highlighted long fallow disorder where AM have died out through lack of host plant roots during long fallow periods. As cropping programs restart after dry years, an unexpected yield drop is likely due to reduce AM levels, making it difficult for the crop to access nutrients. Long fallow disorder is usually typified by poor crop growth (Photo 3). Plants seem to remain in their seedling stages for weeks and development is very slow.

28 Senn A. 2007. Protect your land – use cover crops. DPI NSW. http://archive.dpi.nsw.gov.au/content/agriculture/horticulture/protect

29 Cover cropping practices multiplying nematodes. 2014. http://www.goodfruitandvegetables.com.au/story/3554224/cover-crop-practices-multiplying-nematodes/

Photo 3: *A crop affected by long fallow disorder.*

Source: DAFF

Benefits of good AM levels are:

- improved uptake of P and Zn
- improved crop growth
- improved N_2 fixation
- greater drought tolerance
- improved soil structure
- greater disease tolerance

In general, the benefits of AM are greater at lower soil P levels because AM increase a plant's ability to access this nutrient. Crops with higher dependency benefit more from AM (Table 4). [30]

Table 4: *The dependency of various crop species on mycorrhiza (value decreases as the phosphorus level of the soil increases)*

Mycorrhiza dependency	Potential yield loss without mycorrhiza (%)	Crops
Very high	Greater than 90	Linseed
High	60–80	Sunflower, mungbean, pigeon pea, maize, chickpea
Medium	40–60	Sudan, sorghum, soybean
Low	10–30	Wheat, barley, triticale
Very low	0–10	Panicum, canary
Nil	0	Canola, lupins

Source: DAFF

1.3 Fallow weed control

Paddocks with well-managed fallow periods significantly lower the risk of poor crop and financial performance. The best form of weed control is rotation and careful selection of paddocks largely free from winter weeds (Photo 4).

When sowing dual purpose varieties early, choose a paddock with low weed numbers and control weeds prior to the first grazing. Strategic grazing can be used to help manage weeds. Always check grazing withholding periods before you apply post-emergent herbicides when planning to graze the crop. [31]

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

31 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

Photo 4: *Spraying weeds when small is the key to effective long fallow.*

Source: AGRONOMO

Paddocks generally have multiple weed species present at the same time, making weed control decisions more difficult and often involving a compromise after assessment of the prevalence of key weed species. Knowing your paddock and controlling weeds as early as possible are important for good control of fallow weeds. Information is included for the most common problem weeds; however, for advice on individual paddocks you should contact your agronomist.

Benefits of fallow weed control are significant:

- Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer before in a long fallow) is integral to winter cropping, particularly so as the climate moves towards summer-dominant rainfall.
- Modelling studies show that the highest return on investment in summer weed control is for lighter soils or in situations where soil water that would support continued weed growth is present. [32]

1.3.1 Controlling summer weeds

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

Summer weed control can be expensive but is necessary to prevent problems with excessive growth and/or moisture and nitrogen loss from the soil. When using herbicides:

- Water rates should be kept high (at least 60 litres per hectare).
- Add a surfactant and/or spraying oil to all post-emergent treatments unless otherwise directed on the label.
- Do not spray stressed plants.
- Spray grazing can be effective at high stocking rates.
- Glyphosate, 2,4-D, metsulfuron, atrazine and triclopyr are the most common herbicides used for summer weed control.
- Where summer grasses are present, glyphosate at rates around 2 L/ha are generally required.

32 GRDC (2012) Summer fallow—make summer weed control a priority. GRDC Fact Sheet January 2012.

- Metsulfuron provides cheap control of wireweed, triclopyr is generally preferred for melon control and atrazine for small crumbweed (also known as mintweed or goosefoot).
- 2,4-D controls a wide range of broadleaved weeds and is preferred if stock are available for spray grazing. The ester formulations are usually more effective for summer weed control because they are oil soluble and more able to penetrate the waxy surfaces or stubble.
- Moisture stress in weeds is common in summer and reduces the effectiveness on most herbicides. This can be partially overcome by spraying early in the morning. However at this time of day, inversions may be present which could lead to excessive drift. Avoid spraying during still conditions. [33]

1.3.2 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 5).

Photo 5: *Broad-leafed weeds and grasses form a green bridge in paddock.*

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.
- Diseases and insects can quickly spread from the green bridge, jeopardising crops and current control methods, including the effectiveness of chemicals and genetic breeding for resistance.
- Effective control of pest and disease risks requires neighbours to work together to eradicate weeds and crop volunteers simultaneously.
- Weed growth during summer and autumn depletes soil moisture and nutrients that would otherwise be available to following crops and can have an allelopathic effect. [34]

VIDEOS

WATCH: GCTV5: Managing summer fallow.

MORE INFORMATION

Green bridge management fact sheet

Summer fallow weed management: A reference manual for grain growers and advisers in the southern and western grains regions of Australia.

Summer weeds - DAFWA

33 Peltzer S, Douglas A, Borger C. (2016). Summer Weeds. Department of Agriculture and Fisheries Western Australia. https://www.agric.wa.gov.au/postharvest/summer-weeds?page=0%2C0

34 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, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2010/01/grdc-fs-greenbridge

1.3.3 Management strategies

How farming country is managed in the months or years before sowing can be more important in lifting water use efficiency (WUE) than in-crop management. Of particularly high impact are strategies that increase soil capture and storage of fallow rainfall to improve crop reliability and yield.

Practices such as controlled traffic farming and long term no-till seek to change the very nature of soil structure to improve infiltration rates and improve plant access to stored water by removal of compaction zones.

Shorter term management decisions can have an equal or even greater impact on how much plant available water (PAW) is stored at sowing. These include decisions such as crop sequence/rotation that dictate the length of the fallow and amount of stubble cover, how effectively fallow weeds are managed, stubble management and decisions to till/not to till at critical times.

While many factors influence how much plant available water is stored in a fallow period, good weed management consistently has the greatest impact. [35]

For more information on managing weeds, see Section 6: Weed control.

1.3.4 Stubble retention

Key points:

- Triticale stubble is coarser than either wheat or barley. [36]
- 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 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 6).

Photo 6: *Triticale sown into stubble.*

35 GRDC. (2014). Summer fallow weed management. https://grdc.com.au/Resources/Publications/2014/05/Summer-fallow-weed-management

36 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

Source: Kaspar T in MCCC

Summer rainfall and warmer conditions promote decomposition of stubble.

Reducing erosion risk

One of the main benefits of stubble retention is reduced soil erosion. Retaining stubble decreases erosion by lowering wind speed at the soil surface and decreasing runoff. At least 50% or more ground cover is required to reduce erosion. It is generally considered that 50% ground cover is achieved by 1 t/ha of cereal stubble, 2 t/ha of lupin stubble and 3 t/ha of canola stubble.

Increasing soil water content

A major advantage of retaining stubble is that it increases soil water content by decreasing runoff and increasing infiltration (Figure 4). The actual benefits depend on the timing and intensity of rainfall as well as the quantity and orientation of stubble. Late summer – early autumn rains have more chance of improving the germination and establishment of the next crop. In addition, increased infiltration of water over summer can result in greater nitrogen mineralisation and availability for the subsequent crop.

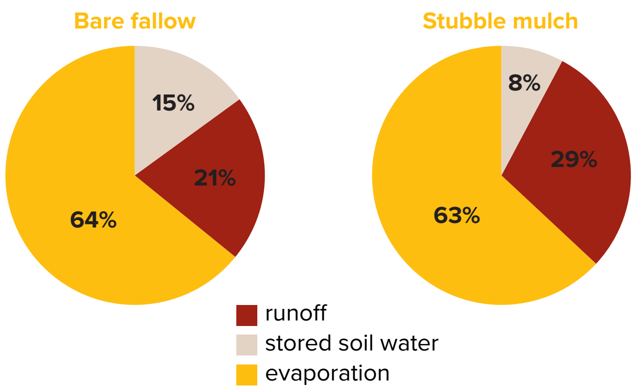


Figure 4: *Retained stubble leads to more stored soil water, mostly due to a reduction in runoff.*

Source: Felton et al. 1987, reproduced in Scott et al. 2010 in Soilquality.org.

Increasing soil carbon

Retaining stubble increases the input of carbon to soil. Stubble is approximately 45% carbon by weight and represents a significant input of carbon to soil. It can take decades for retaining stubble to increase the amount of soil organic carbon. After 10 years, stubble retention generated 2 t/ha more soil organic carbon than stubble burnt plots to a depth of 10 cm in a red chromosol during cropping trials with ley pasture rotations in NSW. After 25 years the inclusion of a clover pasture in the rotation in the same trial had a greater effect on soil organic carbon increases even with tillage compared to stubble retention. Retaining stubble may only increase soil carbon where it is coupled with cultivation but not with direct drilling.

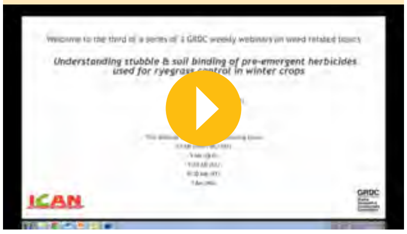
The carbon to nitrogen ratio (C:N) of residues is an important factor in determining the contribution they will make to carbon sequestration as it governs how quickly residues decompose. Pulse residues (C:N 20:1 to 41:1) are more decomposable than cereal residues (C:N 45:1 to 178:1). Faster decomposition may improve nutrient availability for the following crop, but reduce the sequestration of carbon from residues into soil.

VIDEOS

WATCH: Managing Stubble.

WATCH: Stubble height part 1 and part 2.

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



Other benefits of stubble retention

Retaining stubbles returns nutrients to the soil, the amounts depend on the quality and quantity of stubble. Cereal 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 and water holding capacity. These benefits are greater when integrated no till practices. [37]

Management practices affecting stubble cover

Stubble burning, grazing and cultivation are the main management practices with the potential to reduce stubble cover. A single tillage operation using a chisel plough, for example, can reduce stubble coverage by 30 – 40 % (Table 5).
It is recommended that stubble cover be maintained as long as possible in the fallow, and that planting and fertilising machinery be adapted to minimise disturbance. Where cultivation is required in order to control herbicide resistant weeds, this should be carried out as a one-off operation. [38]

Table 5: *Estimated reduction in cereal stubble cover from different tillage operations (reproduced from Measuring stubble cover: Photo standards for winter cereals).*

Implement	Residue buried by each tillage operation (%)	
	Fresh Stubble	Old (brittle) stubble
Disc Plough	60 – 80	80 – 90
Chisel Plough	30 – 40	40 – 60
Blade Plough	20 – 30	30 – 50
Boomspray	negligible	negligible

Source: Soilquality

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

1.4 Fallow chemical plant-back effects

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 6 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. [39]

Table 6: *Residual persistence of common pre-emergent herbicides, and note residual persistence in broad-acre trials and paddock experiences.* [40]

Herbicide	Half-life (days)	Residual persistence and prolonged weed control

37 Soilquality.org. Benefits of retaining stubble – WA. http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble

38 Soilquality.org. Benefits of retaining Stubble – Queensland. http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld

39 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

40 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

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

For up to date recommendations on herbicide plant-back intervals, visit the AVPMA website.

1.4.1 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. [41]

1.4.2 Herbicide residues in soil – an Australia wide study

The move to conservation tillage and herbicide-tolerant crop cultivars means that many farmers are relying on herbicides for weed control more than ever before. Despite the provision of plant-back guidelines on herbicide product labels, site-specific factors such as low rainfall, constrained soil microbial activity and non-ideal pH may cause herbicides to persist in the soil beyond usual expectations. Because of the high cost of herbicide residue analysis, information about herbicide residue levels in Australian grain cropping soils is scarce.

In addition, little is known about how herbicides affect soil biological processes and what this means for crop production. This is especially the case for repeated applications over multiple cropping seasons. In Australia, herbicides undergo a rigorous assessment by the Australian Pesticides and Veterinary Medicines Association (APMVA) before they can be registered for use in agriculture. However, relatively little attention is given to the on-farm soil biology – partly because we are only now beginning to grasp its complexity and importance to sustainable agriculture. Although a few tests are mandatory, such as earthworm toxicity tests and effects on soil respiration, functional services provided by soil organisms such as organic matter turnover, nitrogen cycling, phosphorus solubilisation and disease suppression are usually overlooked.

GRDC co-funded a five year project (DAN00180) to better understand the potential impacts of increased herbicide use on key soil biological processes. This national project, co-ordinated by the NSW Department of Primary Industries with partners in Western Australia (WA), South Australia (SA), Victoria (Vic) and Queensland (Qld), is focussed on the effect of at least six different herbicide classes on the biology and function of five key soil types across all three grain growing regions.

Below are the results of a field survey of herbicide residues in 40 cropping soils prior to sowing and pre-emergent herbicide application in 2015 (Table 7). Recommendations are given to minimise potential impacts of herbicide residues on productivity and soil sustainability.

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

Table 7: *Residue loads (average and maximum) of herbicide active ingredients (a.i.) in the 0–30 cm soil profile of paddocks by region.*

Herbicide	Estimated average load across all sites (kg a.i./ha)*			Estimated maximum load detected (kg a.i./ha)*		
	NSW-Qld	SA	WA	NSW-Qld	SA	WA
AMPA	0.91	0.95	0.92	1.92	1.97	2.21
Glyphosate	0.56	0.48	0.79	2.05	1.05	1.75
Trifluralin	0.08	0.11	0.53	0.14	0.26	1.34
Diflufenican	0.01	0.03	0.04	0.02	0.05	0.09
Diuron	0.14	0.05	0.17	0.16	0.05	0.29
2, 4-D	0.20	0.02	0.01	1.00	0.05	0.02
MCPA	0	0	0	0	0	0
Atrazine	0.02	0.03	0.02	0.03	0.05	0.02
Simazine	0	0.04	0	0	0.05	0
Fluroxypyr	0.03	0	0	0.03	0	0
Dicamba	0	0	0	0	0	0
Triclopyr	0	0.04	0.01	0	0.07	0.01
Chlorsulfuron	0	0	0	0	0	0
Sulfometuron-methyl	0	0	0	0	0	0
Metsulfuron-methyl	0	0	0	0	0	0
Triasulfuron	0	0	0	0	0	0

*Calculated by multiplying mass concentration (mg/kg) detected by area and average bulk density (derived from soilquality.org) for each soil layer

Source: NSW DPI

MORE INFORMATION

Herbicide residues in soils – are they an issue?

Weed control in winter crops.

Conclusions

- Glyphosate, trifluralin and diflufenican are routinely applied in grain cropping systems and their residues, plus the glyphosate metabolite AMPA, are frequently detected at agronomically significant levels at the commencement of the winter cropping season.
- The risk to soil biological processes is generally minor when herbicides are used at label rates and given sufficient time to dissipate before re-application.
- However, given the frequency of glyphosate application, and the persistence of trifluralin and diflufenican, further research is needed to define critical thresholds for these chemicals to avoid potential negative impacts to soil function and crop production. [42]

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

1.5 Seedbed requirements

Seedbed preparation for triticale is very similar to wheat. As with all cereals, triticale should be planted into a firm seedbed and placed near moisture. [43] A good seedbed should be weed, disease and insect free. To minimize weeds, prepare the seedbed so it is as clean as possible before planting, and be sure to practice crop rotation. Planting early will help with the quick establishment of a triticale stand and may stave off early weed pressure. [44]

42 Rose M, Van Zwieten L, Zhang P, Nguyen D, Scanlan C, Rose T, McGrath G, Vancov T, Cavagnaro T, Seymour N, Kimber S, Jenkins A, Claassens A, Kennedy I. (2016). GRDC Update Paper: Herbicide residues in soils – are they an issue? https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/herbicide-residues-in-soils-are-they-an-issue-northern

43 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

44 UVM. Triticale. Northern grain growers. http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

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.

There are several approaches that can be used in achieving a good seedbed preparation. The deciding factor in choosing 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:

- Conventional technique
- Mouldboard ploughing + drilling
- Minimal tillage
- Shallow tillage
- Direct drilling

The technique used depends on many different factors, e.g. harvest residues, the equipment available, soil type, climate, labour requirement, etc (Figure 5).

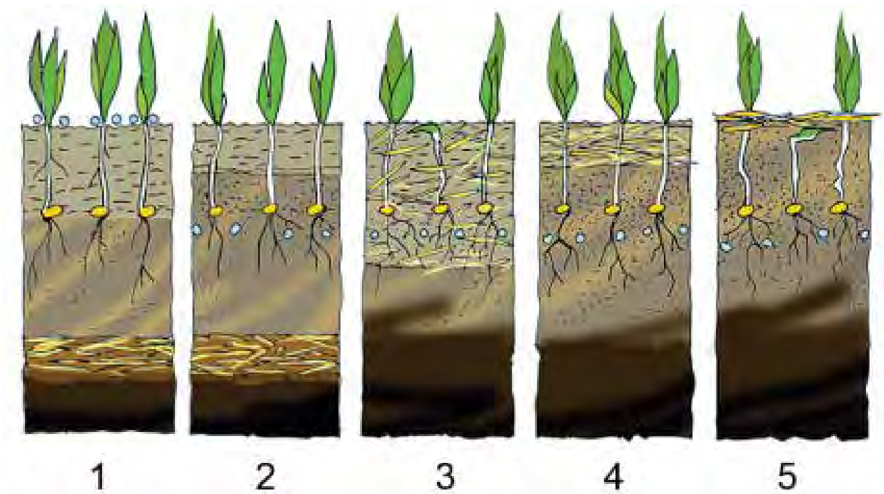


Figure 5: *Diagram demonstrating the results of different seedbed preparation techniques.*

Source: Vaderstad

The seedbed and sowing using different techniques:

1. **Conventional technique** - ploughing in of straw, cultivation to sowing depth with a tine/disc cultivator, conventional drilling, fertiliser spreading.
2. Ploughing in of straw, **shallow cultivation** and drilling, where seed and fertiliser are placed in the soil simultaneously.
3. **Minimal tillage** – tillage of straw by cultivator and drilling, where seed and fertiliser are placed simultaneously in the soil/straw layer.
4. **Shallow tillage –** shallow burial of straw at the surface and drilling, where seed and fertiliser are placed simultaneously in the soil/straw layer.
5. **Direct drilling** – drilling, where seed and fertiliser are placed simultaneously without prior soil tillage. 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. [45]

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

Cereals can be conventionally sown or direct drilled into a weed free seedbed from March to mid June.

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. [46]

1.5.1 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 – hardsetting or crusting (Photo 7). 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. The unstable soil structure once wet, 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 7: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium.*

Source: Soilquality.org

46 Agriculture Victoria. Managing winter cereals.

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. [47]

1.5.2 Tillage

Tillage mixes and buries soil amendments and crop residue, eliminates existing vegetation, reduces pest populations, promotes mineralisation of soil organic matter, and creates a seedbed that facilitates mechanical planting and seed-to-soil contact.

The use of minimum soil disturbance has advantages for the production of triticale. One study noted a slight yield advantage for triticales grown under zero tillage. [48]

Research shows one-time tillage with chisel or offset disc in long-term, no-tillage helped to control winter weeds, and slightly improved grain yields and profitability, while retaining many of the soil quality benefits of no-till farming systems (Photo 8). Tillage reduced soil moisture at most sites; however, this decrease in soil moisture did not adversely affect productivity. This could be due to good rainfall received after tillage and prior to seeding and during the crop of that year. The occurrence of rain between the tillage and sowing or immediately after sowing is necessary to replenish soil water lost from the seed zone. This suggests the importance of timing of tillage and of considering the seasonal forecast. Future research will determine the best timing for strategic tillage in no-till systems (Photo 9). [49] Note that these results are from one season and research is ongoing, so any impacts are likely to vary with subsequent seasonal conditions.

Photo 8: *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: GRDC

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

48 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

49 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 Feb. 2013, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2013/02/tillage-impact-in-long-term-no-till

Photo 9: *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: GRDC

However, tillage can also result in increased soil erosion and surface water eutrophication. During the past 30 years, much progress has been made in reducing tillage. No-tillage crop production has increased 2.5-fold from about 45 million ha worldwide in 1999 to 111 million ha in 2009. One downside of this trend is increased use of herbicides for weed suppression. [50]

In general, pre-plant tillage to prepare the seedbed, control weeds, and disrupt insect and disease life cycles improves crop establishment. However, with cereal rye or other small grains, no-till establishment is an effective option that allows maintenance of the no-till system. Conventional seedbeds are prepared by plowing, disking, and harrowing the soil prior to seeding. Seeding depth depends upon the species being sown. No-till seedings are suitable for highly erodible soils and for late-season establishment. [51]

1.6 Soil moisture

Triticale performs well under rain fed conditions throughout the world and excels when produced under good soil fertility and irrigation. [52] Triticale is grown in areas with an annual average rainfall of about 300 mm through to at least 900 mm. Very little triticale is irrigated. [53]

1.6.1 Dryland

Water availability is a key limiting factor for cereal production in the grainbelt of Australia. Varieties with improved adaptation to water-limited conditions are actively sought and studies have been carried out to identify the physiological basis of the adaptive traits underpinning this advantage.

VIDEOS

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

MORE INFORMATION

GRDC Strategic Tillage Tips and Tactics fact sheet.

50 Ryan, M. R., Mirsky, S. B., Mortensen, D. A., Teasdale, J. R., & Curran, W. S. (2011). Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. *Weed science*, *59*(2), 238–246.

51 Cover crops for conservation tillage systems. http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/cover-crops-for-conservation-tillage-systems

52 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

53 Cooper KV, Jessop RS, Darvey NL in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org. http://www.fao.org/docrep/009/y5553e/y5553e00.htm

Soil water tool

Plant available soil water graphs show the amount of soil water accumulated from the start of summer (1 November) through the grain growing season and can be used as a tool in the seasonal decision making process.

Plant available soil water is modelled using the Ritchie two-layer fallow evaporation model described in Ritchie, J.T. 1972, Model for predicting evaporation from a row crop with incomplete cover.

While plant available soil water graphs can help create a narrative for the progress of a crop and aid key in-season decision-making, other key factors also need to be considered for any given crop to arrive at an accurate picture. These include:

- Soil status and characteristics including stored soil moisture, soil water-holding capacity and any barriers to infiltration.
- Stored nitrogen and other nutrient availabilities.
- Factors such as non-wetting, water-logging through topography or impermeable layers, leaching or dispersible clays in the soil.

The timing and event intensity of rain during the growing season can also greatly influence the conversion of rainfall to biomass and yield.

To use the soil water tool, select a weather station, a soil type and whether the model is for a fallow or cropped situation from the drop-down lists below. Graphs can be downloaded and saved by clicking on the three horizontal lines to the right of the graph title.

Maps of plant available soil water, updated monthly in the early part of the growing season, can be viewed and downloaded from our Seasonal climate information page. [54]

MORE INFORMATION

Soil water tool - DAFWA

1.6.2 Irrigation

Irrigation is the artificial application of water to land for the purpose of agricultural production. Effective irrigation will influence the entire growth process from seedbed preparation, germination, root growth, nutrient utilisation, plant growth and regrowth, yield and quality.

The key to maximising irrigation efforts is uniformity. The producer has a lot of control over how much water to supply and when to apply it but the irrigation system determines uniformity. Deciding which irrigation systems is best for your operation requires a knowledge of equipment, system design, plant species, growth stage, root structure, soil composition, and land formation. Irrigation systems should encourage plant growth while minimising salt imbalances, leaf burns, soil erosion, and water loss. Losses of water will occur due to evaporation, wind drift, run-off and water (and nutrients) sinking deep below the root zone.

Proper irrigation management takes careful consideration and vigilant observation.

Irrigation allows primary producers;

- to grow more pastures and crops
- to have more flexibility in their systems/operations as the ability to access water at times when it would otherwise be hard to achieve good plant growth (due to a deficit in soil moisture) is imperative. Producers can then achieve higher yields and meet market/seasonal demands especially if rainfall events do no occur.
- to produce higher quality crops/pastures as water stress can dramatically impact on the quality of farm produce
- to lengthen the growing season (or in starting the season at an earlier time)
- to have 'insurance' against seasonal variability and drought.
- to stock more animals per hectare and practice tighter grazing management due to the reliability of pasture supply throughout the season

54 DAFWA (2016). Soil water tool. https://www.agric.wa.gov.au/climate-weather/soil-water-tool#?station=10115&soil=3&groundCover=1

- to maximise benefits of fertiliser applications. Fertilisers need to be 'watered into' the ground in order to best facilitate plant growth.
- to use areas that would otherwise be 'less productive'. Irrigation can allow farmers to open up areas of their farms where it would otherwise be 'too dry' to grow pasture/crops. This also gives them the capability to carry more stock or to conserve more feed.
- to take advantage of market incentives for unseasonal production
- to have less reliance on supplementary feeding (grain, hay) in grazing operations due to the more consistent supply & quality of pastures grown under irrigation
- to improve the capital value of their property. Since irrigated land can potentially support higher crops, pasture and animal production, it is considered more valuable. The value of the property is also related to the water licensing agreements or 'water right'.
- to cost save/obtain greater returns. The cost benefits from the more effective use of fertilisers and greater financial benefits as a result of more effective agricultural productivity (both quality and quantity) and for 'out of season' production are likely. [55]

MORE INFORMATION

IrrigateWA

Irrigation has also been found to be effective in increasing both shoot Zn content and Zn efficiency of cereal cultivars. It has been suggested that plants become more sensitive to Zn deficiency under rainfed than irrigated conditions. [56]

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. However, in most of the newer varieties lodging is not considered a problem. The likelihood of lodging is increased by high rates of nitrogen fertiliser and under irrigated conditions (Table 8). [57]

Table 8: *Lodging scores in NVT trials, 2008. NOTE: A score of 0 means the variety was not prone to lodging and a score of 5 means that the variety is prone to heavy lodging.* [58]

Variety	Score
Bogong⦇D	0/5
Jaywick⦇D	3/5
Tahara	3/5
Tobruk⦇D	0/5
Canobolas⦇D	0/5
Berkshire⦇D	1/5
JRCT 101	0/5
Yukuri	5/5
Rufus	5/5

1.7 Yield and targets

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

55 Agriculture Victoria. About Irrigation. http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/irrigation/about-irrigation

56 Ekiz, H., Bagci, S. A., Kiral, A. S., Eker, S., Gültekin, I., Alkan, A., & Cakmak, I. (1998). Effects of zinc fertilisation and irrigation on grain yield and zinc concentration of various cereals grown in zinc-deficient calcareous soils. *Journal of Plant Nutrition*, *21*(10), 2245–2256.

57 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

58 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

The average grain yield of triticale is about 2.5 tonnes/ha, although these yields vary locally from less than 1 tonne/ha in lower rainfall areas and areas with soil problems to more than 7 tonnes/ha in higher rainfall areas with more fertile soils. [59]

In dry springs triticale yields are 10–15% below wheat, due to triticale's longer grain filling period. [60] However, under ideal conditions, researchers have found that triticale can out-yield wheat and barley and sometimes oats. [61]

Observed traits suggested for the higher yields in triticale than wheat include greater early vigour, a longer spike formation phase with same duration to flowering, reduced tillering, increased remobilization of carbohydrates to the grain, early vigorous root growth and higher transpiration use efficiency. [62]

IN FOCUS

Triticale v Durum wheat: a yield comparison in Mediterranean-type environments

The productivity of modern triticales makes them increasingly viable as an alternative small grain cereal crop to durum wheat in the Mediterranean environment. A comparison between the two species was performed, based on a substantial number of cultivars tested in 20 field experiments in Italy. Grain yield per environment ranged from 3.4 to 7.7 t/ha^{-1}; in 11 of the environments, the triticales as a group out-yielded the durum wheats, while in the remaining nine, the two species yielded equally. The superiority of triticale derived from its combination of setting a higher number of grains per unit area (reflecting greater ear fertility) and a similar per unit grain weight. Triticale is well adapted to the Mediterranean environment, provided that sowing density is no less than 300 seeds per m^2, because ear fertility contributes more than tillering capacity to the number of grains set per m^2. In the 20 environments tested, the generally favourable pre-anthesis period in terms of temperature and water availability assured triticale the possibility of realizing a grain yield at least comparable to that of durum wheat. At the same time triticale out-yielded durum wheat when its flowering time fell within an optimal window, and where the post-anthesis environment was not too stressful. High ear fertility should be treated as an important trait in the breeding of small grain cereals, because of its positive influence over both yield potential and yield stability. [63]

Before planting, identify the target yield required to be profitable:

- Do a simple calculation to see how much water you need to achieve this yield
- Know how much soil water you have (treat this water like money in the bank).
- Think about how much risk your farm can take.
- Consider how this crop fits into your cropping plan, will the longer-term benefits to the system outweigh any short-term losses?

59 Cooper KV, Jessop RS, Darvey NL in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org. http://www.fao.org/docrep/009/y5553e/y5553e00.htm

60 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

61 Agriculture Victoria (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

62 Bassu, S., Asseng, S., & Richards, R. (2011). Yield benefits of triticale traits for wheat under current and future climates. *Field Crops Research*, *124*(1), 14–24.

63 Motzo, R., Pruneddu, G., Virdis, A., & Giunta, F. (2015). Triticale vs durum wheat: A performance comparison in a Mediterranean environment. *Field Crops Research*, *180*, 63–71.

- Avoiding a failed crop saves money now and saves stored water for future crops. [64]

Estimating crop yields

Accurate, early estimation of grain yield is an important skill. Farmers require accurate yield estimates for a number of reasons:

- Crop insurance purposes
- Delivery estimates
- Planning harvest and storage requirements
- Cash-flow budgeting

Extensive personal experience is essential for estimating yield at early stages of growth. As crops near maturity, it becomes easier to estimate yield with greater accuracy.

Estimation methods

There are many methods available for farmers and others to estimate yield of various crops. Some are straightforward whereas others are more complicated. The method presented in this article is one that can be undertaken relatively quickly and easily Steps are as follows:

1. Select an area that is representative of the paddock. Using some type of measuring rod/tape, measure out an area 1 meter square and count the number of heads/pods.
2. Do this 5 times to get an average of the crop.
3. Count the number of grains in at least 20 heads/pods and average.
4. Using Table 1 below determine the grain weight for the crop concerned and follow through the calculation outlined below

Accuracy of yield estimates depends upon an adequate number of counts being taken so as to get a representative average of the paddock. The yield estimate determined will only be a guide and assumptions made from the estimates contain a degree of uncertainty.

This type of yield estimation is one of the easiest and quickest to complete and should be able to be used in a number of situations on a grain growing property. Grain losses both before and during harvest can be significant and an allowance for 5–10 per cent loss should be included in your final calculations. [65]

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

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

65 Agriculture Victoria. Estimating crop yields; a brief guide. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/estimating-crop-yields-a-brief-guide

in a given season, Yield Prophet subscribers may avoid over- or under-investing in their crop.

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

1.7.1 Seasonal outlook

Enabling farm businesses to better manage the increasing seasonal variability is critical for the success of the Western Australian agrifood sector. The development of improved weather data and seasonal forecasting tools are designed to assist growers to better manage and take full advantage of the opportunities related to seasonal variability and climate change.

Mobile applications (apps) are providing tools for ground-truthing precision agriculture data. Apps and mobile devices are making it easier to collect and record data on-farm. The app market for agriculture is evolving rapidly, with new apps becoming available on a regular basis. For more information, download the GRDC Update paper, Managing data on the modern farm. [66]

Seasonal Climate Outlook

The Season Climate Outlook (SCO) is a monthly newsletter that summarises climate outlooks for the next three months produced by DAFWA's Statistical Seasonal Forecast (SSF) system specifically for the Western Australian grain belt, and by the Australian Bureau of Meteorology. It provides a review of recent climate indicators, including ENSO (El Niño Southern Oscillation), the Indian Ocean Dipole, the Southern Annular Mode, as well as local sea surface temperature and pressures systems. At appropriate times of year it also includes an overview of the rainfall outlook for the growing season produced by the SSF. [67]

See also, the DAFWA's Seasonal climate information.

66 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2013/02/managing-data-on-the-modern-farm

67 DAFWA (2016). Seasonal Climate Outlook. https://www.agric.wa.gov.au/newsletters/sco

CropMate

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

Download CropMate from the App Store on iTunes.

CliMate

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 Southern Oscillation status. It is designed for decision makers such as farmers whose businesses rely on the weather.

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

One of the CliMate tools, 'Season's progress?',uses long-term (1949 to present) weather records to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years.

It explores the readily available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons.

Crop progress and expectations are influenced by rainfall, temperature and radiation since planting. Season's progress? provides an objective assessment based on long-term records:

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

For inputs, Season's progress? asks for the weather variable to be explored (rainfall, average daily temperature, radiation, heat sum with base temperatures of 0, 5, 10, 15 and 20°C), a start month and a duration.

As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation. [68]

MORE INFORMATION

Australia Bureau of Meteorology Climate outlooks

Climate kelpie.

1.7.2 Fallow moisture

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. As a farmer, you have some control over the stored soil water; you can measure how much you have 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. [69]

68 Australian CliMate—Climate tools for decision makers, https://climateapp.net.au/

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

HowWet?

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

HowWet?:

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

This information aids in the decision about what crop to plant and how much N fertiliser to apply. Many grain growers are in regions where stored soil water and nitrate at planting are important in crop management decisions.

Questions this tool answers:

How much longer should I fallow? If the soil is near full, maybe the fallow can be shortened.

Given my soil type and local rainfall to date, what is the relative soil moisture and nitrate-N accumulation over the fallow period compared with most years? Relative changes are more reliable than absolute values.

Based on estimates of soil water and nitrate-N accumulation over the fallow, what adjustments are needed to the N supply?

Inputs

- A selected soil type and weather station
- An estimate of soil cover and starting soil moisture
- Rainfall data input by the user for the stand-alone version of HowOften?

Outputs

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

Reliability

HowWet? uses standard water-balance algorithms from HowLeaky? and a simplified nitrate mineralisation based on the original version of HowWet? Further calibration is needed before accepting with confidence absolute value estimates.

Soil descriptions are based on generic soil types with standard organic carbon (C) and C/N ratios, and as such should be regarded as indicative only and best used as a measure of relative water accumulation and nitrate mineralisation. [70]

1.7.3 Water Use Efficiency

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

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

70 Australian CliMate—How Wet/N, https://climateapp.net.au/A04_HowWetN

Triticale uses water more efficiently than oats and rye. [71]

One study found that triticale had similar Water Use Efficiency and resulting yield to wheat under varying soil moisture conditions. [72]

Research in southern Australia found that total water use of triticale was less than that of wheat and rye, particularly at the higher rates of N. WUE of triticale was also higher at all levels of N and increased with increasing N application, whereas the WUE in wheat and rye didn't increase after 50kgN/ha. [73]

One study in a Mediterranean climate attributed high Water Use Efficiency and yield to triticale's stomatal conductance. [74]

IN FOCUS

Triticale grain yield and physiological response to water stress

Water availability in semi-arid regions is increasingly becoming threatened by erratic rains and frequent droughts leading to over-reliance on irrigation to meet food demand. Improving crop Water Use Efficiency (WUE) has become a priority. A two-year study was carried out with four moisture levels, ranging from well-watered (430–450 mm) to severe stress (SS) (220–250 mm), combined with four commercial triticale genotypes grown under field conditions in a hot, arid, steppe climate in South Africa. The results showed that moisture level significantly influenced grain yield and intrinsic WUE in triticale. Well-watered conditions increased grain yield, which ranged from 3.5 to 0.8 t ha−1and4.9–1.8 t ha−1in 2013 and 2014 respectively. Intrinsic WUE increased with decreasing moisture level. Flag leaf photosynthesis and pre-anthesis assimilates contribute much less carbon to grain filling under water stress than previously thought. [75]

CSIRO and research partners, including the GRDC, working on the National Water Use Efficiency (WUE) Initiative have identified ways to improve yield through better WUE, in some cases by as much as 91 per cent. The results of the WUE Initiative have demonstrated an increase in the long term average winter crop yield without increasing input costs, lifting average Australian wheat yield by around 25% across all regions. They have also shown an increase in the long term average yields of winter grain crops including barley and canola. Improved summer fallow management, including weed management and stubble retention can lead to a 60 per cent increase in grain yield. The use of a vetch (legume) break crop following two consecutive grain crops can lead to an increase between 16–83%. The results also revealed that by matching nitrogen supply to the soil type it is possible to achieve a increase of up to 91%. [76]

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.

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71 Mergoum *et al*. 2004 – in Tshewang S. (2011). Frost tolerance in Triticale and other winter cereals at flowering. https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

72 Aggarwal, P. K., Singh, A. K., Chaturvedi, G. S., & Sinha, S. K. (1986). Performance of wheat and triticale cultivars in a variable soil—water environment II. Evapotranspiration, Water Use Efficiency, harvest index and grain yield. *Field Crops Research*, *13*, 301–315.

73 Golding, J. B. Restricted tillering in triticale cv. currency-an impediment to grain yield? http://www.regional.org.au/au/asa/1989/contributed/crop/p1-20.htm

74 Motzo, R., Pruneddu, G., & Giunta, F. (2013). The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment. *European Journal of Agronomy*, *44*, 87–97.

75 Munjonji, L., Ayisi, K. K., Vandewalle, B., Haesaert, G., & Boeckx, P. (2016). Combining carbon-13 and oxygen-18 to unravel triticale grain yield and physiological response to water stress. *Field Crops Research*, *195*, 36–49.

76 CSIRO. Researching Water Use Efficiency for increased grain yield. http://www.csiro.au/en/Research/AF/Areas/Sustainable-farming/Soil-water-landscape/WUE-Initiative

- 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.

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). [77]

The French–Schultz approach

The French-Schultz model is 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. [78]

Modified French-Schultz approach

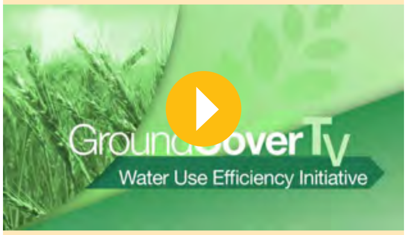
In Western Australia water evaporation losses can range from 40–90 mm on Mallee soils along the south coast through to 130 mm on the deep sands common at Wongan Hills. WUE and potential yield estimates will be inaccurate if the evaporation component of the French and Schultz equation is not adjusted to suit the agronomic and climatic characteristics of the system being assessed.

77 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

78 GRDC (2009) Water Use Efficiency—Converting rainfall to grain. GRDC Fact Sheet. Water Use Efficiency Fact Sheet, GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2010/02/grdc-fs-wateruseefficiencysouthwest

VIDEOS

WATCH: GCTV12: Water Use Efficiency Initiative.



WATCH: GCTV10: Grazing stubbles and Water Use Efficiency.

MORE INFORMATION

Water Use Efficiency of grain crops in Australia: principles, benchmarks and management

Making the most of available water in wheat production.

The French and Schultz equation has been modified in several important ways to adapt it to rainfall patterns and soils of the WA grain belt. The growing season rainfall (GSR) of the 'crop water use' component was changed to be rainfall from the start of May through to the end of October (instead of April-October as used by French and Schultz).

One-third of out-of-season (OSR) (January-April) rainfall in the 'crop water use' component was also included. This accounts for the fact that about 30% of rainfall falling between January-April is still available in the soil by seeding.

A cap on the 'crop water use' component so that it could not exceed the plant available water capacity (PAWC) of the soil was also introduced. This means that the 'crop water use' component cannot be overestimated in higher rainfall years on soils with relatively low capacity to hold water.

Finally, a sliding scale for the soil evaporation component was introduced which is more suited to WA conditions with soil evaporation set at 130 mm when GSR is greater than 180 mm and 90 mm when GSR is less than 180 mm. This ensures that Water Use Efficiency is not underestimated in low-rainfall years.

In the modified French and Schultz equation:

Crop yield = (May-Oct rainfall + 0.3 (Jan-April rainfall)) – soil evaporation

For soil evaporation the following qualifications are used:

- If GSR >180 mm then soil evaporation = 130 mm
- If GSR < 180 mm then soil evaporation = 90 mm
- If GSR+OSR > PAWC then GSR+OSR = PAWC. [79]

The modified French-Schultz equation can result in less variation between actual and potential yield values – most likely due to the cap placed on 'crop water use' relative to soil PAWC. [80]

Challenging the French-Schultz approach

The seasonality of rainfall, together with frost risk, drives the choice of cultivar and sowing date, resulting in flowering time.

Crops are therefore exposed to contrasting climatic conditions during the critical period for grain formation; i.e. a window of ~20 days before and 10 days after flowering, which affects yield potential and WUE.

Understanding how those climatic conditions affect crop processes and how they vary from 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. [81]

1.7.4 Nitrogen use efficiency

Key points:

- Improving NUE begins with identifying and measuring meaningful NUE indices and comparing them with known benchmarks and contrasting N management tactics.

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79 Oliver Y.M., Robertson M.J., Stone P.J., Whitbread A. (2009) Improving estimates of water-limited yield of wheat by accounting for soil type and within-season rainfall. Crop and Pasture Science 60, 1137–1146.

80 DAFWA. The Agronomy Jigsaw.

81 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

- Potential causes of inefficiency can be grouped into six general categories. Identification of the most likely groups is useful in directing more targeted measurement and helping identify possible strategies for improvement.
- As result of seasonal effects, NUE improvement is an iterative process therefore, consistency in investigation strategy and good record keeping are essential. [82]

Nitrogen use efficiency (NUE) is the efficiency with which soil nitrate-N is converted into grain N. The nitrate-N comes from fertiliser, crop residues, manures, and soil organic matter, but it is the efficiency of conversion of fertiliser into grain that is generally of greatest concern to growers. Efficiency is reduced by seasonal conditions, crop diseases, losses of N from the soil as gases, N leaching or immobilisation of N into organic forms.

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

A balance of nutrients is essential for profitable yields. Fertiliser is commonly needed to add the essential nutrients P and N. Lack of other essential plant nutrients may also limit production in some situations. Knowledge of the nutrient demand of crops is essential in determining nutrient requirements. Soil testing and nutrient audits assist in matching nutrient supply to crop demand. [83]

Nitrogen fertilisers are a significant expense for broadacre farmers so optimising use of fertiliser inputs can reduce this cost. There are four main sources of nitrogen available to crops: stable organic nitrogen, rotational nitrogen, ammonium and nitrate. To optimise plants' ability to use soil nitrogen, growers should first be aware of how much of each source there is. The best method of measuring these nitrogen sources is soil testing. [84]

Recent research in the UK found that triticale had higher biomass and straw yields, lower harvest index and higher total N uptake than wheat. Consequently, triticale had higher N uptake efficiency and higher N use efficiency. [85]

In another study, NUE decreased with increasing N fertiliser rates. At an N supply of 100 kg ha−1 a−1, the NUEs of triticale was 0.14 t dry biomass/kg N. [86]

Optimising nitrogen use efficiency

Nitrogen fertilisers are a significant expense for broadacre farmers so optimising use of fertiliser inputs can reduce this cost. There are four main sources of nitrogen available to crops: stable organic nitrogen, rotational nitrogen, ammonium and nitrate. To optimise plants' ability to use soil nitrogen, growers should first be aware of how much of each source there is. The best method of measuring these nitrogen sources is soil testing. [87]

MORE INFORMATION

The fundamentals of increasing nitrogen use efficiency.

1.7.5 Double crop options

Double cropping is growing a winter and summer crop following one another.

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82 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

83 Schwenke, P Grace, M Bell (2013) Nitrogen use efficiency. GRDC Update Papers 16 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency

84 Soilquality.org. Optimising soil nutrition. http://www.soilquality.org.au/factsheets/optimising-soil-nutrition

85 ROQUES, S., KINDRED, D., & CLARKE, S. (2016). Triticale out-performs wheat on range of UK soils with a similar nitrogen requirement. *The Journal of Agricultural Science*, 1–21.

86 Lewandowski, I., & Schmidt, U. (2006). Nitrogen, energy and land use efficiencies of miscanthus, reed canary grass and triticale as determined by the boundary line approach. *Agriculture, Ecosystems & Environment*, *112*(4), 335–346.

87 Soilquality.org. Optimising soil nutrition. http://www.soilquality.org.au/factsheets/optimising-soil-nutrition

Cool-season annual forages such as triticale are well-suited to double cropped forage. [88]

Planting cool-season annuals following grain harvest is an economical way to produce high-quality forage. Two types of cool-season annual forages that are well-suited to produce double-cropped forage are small grain cereal grasses, such as triticale, oats, cereal rye and wheat, and brassicas which include turnip and radish.

For autumn forage, the general concept is to take advantage of the potential growing degree-days following grain harvest. Ideally, planting a forage double-crop would occur as soon as possible following grain harvest since the growing degree days available for plant growth rapidly decline through the late summer into early autumn. The risk of failure increases with later planting dates. However, establishment costs are often low enough for many of these forages that the successful years often outweigh the years in which failure occurs. [89]

For spring forage, the winter cereals triticale, rye and wheat tend to be the best choices.

1.8 Disease status of paddock

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

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

Crop sequencing is only a part of the integrated management of diseases. Other practices include maintaining sufficient distance from last year's paddock of the same crop or from a paddock with residue infected with a pathogen of the intended crop; the use of high-quality, fungicide-treated seed; planting within the planting window, variety selection, and in-crop fungicide treatments. [90]

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

Paddock selection is an important consideration for crown rot management, in particular, and growers should select paddocks with a low risk of the disease. Paddock risk can be determined by visually assessing crown rot and root-lesion nematode (RLN; see section below) levels in a prior cereal crop, paying attention to basal browning, and/or having soil samples analysed at a testing laboratory. The presence of spores of tan (yellow) spot is also an important consideration, and effective management of this disease in cereals depends on decisions made before sowing.

1.8.1 Soil testing for disease

In addition to visual symptoms, the DNA-based soil test ("PreDicta B™") can be used to assess the disease status in the paddock. Soil samples that include plant residues should be tested early in late summer to allow results to be returned before seeding. This test is particularly useful when sowing susceptible varieties, and for assessing the risk after a non-cereal crop.

88 NebGuide. Annual cool-season forages for late-fall or early-spring double-crop. http://extensionpublications.unl.edu/assets/pdf/g2262.pdf

89 NebGuide. 2015. Annual cool-season forages for late-fall or early-spring double crop. http://extensionpublications.unl.edu/assets/pdf/g2262.pdf

90 M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers, 13 September 2011.

PreDicta B

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 10).

Photo 10: *PreDicta B sample.*

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.

PreDicta B samples are processed weekly between February to mid-May (prior to crops being sown) every year.

PreDicta B is not intended for in-crop diagnosis. See the crop diagnostic webpage for other services.

1.8.2 Cropping history effects

The previous crop will influence levels of both soil- and residue-borne diseases. Important diseases to consider include take-all, crown rot, yellow leaf spot, stripe rust, and wheat streak mosaic virus (Table 9). 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.

For diseases, there has been a focus on management of crown rot and RLN, yellow leaf spot in winter cereals, and the roles that rotational crops play, particularly the winter pulses. 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 diseases, other practices include maintaining sufficient distance from last year's paddock of the same crop or from a paddock with residue infected with a pathogen of the intended crop, the use of high-quality, fungicide-treated seed, planting within the planting window, variety selection, and in-crop fungicide treatments. [91]

Paddock histories likely to result in high risk of disease e.g. crown rot include:

- durum wheat in the past 1–3 years

91 M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers 13 September 2011

- winter cereal or a high grass burden from last season—crown rot fungus survives in winter cereal residues, dense stubble cover or where dry conditions have made residue decomposition slow
- break crops, which can influence crown rot in cereals by manipulating the amount of nitrogen (N) and moisture left in the soil profile
- paddocks that have high levels of N at sowing and/or low stored soil moisture at depth. [92]
- wheat varieties grown in previous year (Photo 1). [93]

Photo 11: *Diseased patches from previous crops vary in size from less than half a metre to several metres in diameter.*

Source: DAFWA

For more information, see Section 9: Diseases.

1.9 Nematode status of paddock

Three major root lesion nematode (RLN) species (*Pratylenchus neglectus*, *P. teres* and *P. thornei*) are found in 5.3 million hectares (or about 60%) of WA's cropping area. Populations are yield-limiting in at least 40% of cropping paddocks (Photo 12). [94]

92 GRDC (2009) Crown rot in cereals. GRDC Fact Sheet May 2009, https://grdc.com.au/__data/assets/pdf_file/0021/210918/grdc-crown-rot-fact-sheet-southern-and-western-regions.pdf.pdf

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

94 Collins S, Wilkinson C, Kelly S, Hunter H and DeBrincat. (2014). Root lesion nematode has a picnic in 2013). DAFWA. http://www.giwa.org.au/pdfs/2014/Presented_Papers/Collins%20Sarah_Root%20lesion%20nematode%20has%20a%20picnic%20in%202013_PAPER%20DR.pdf

Photo 12: *Paddock showing patches caused by root lesion.*

Source: DAFWA

Roots of triticale in nematode infested soil have been found to contain fewer nematodes than other cereals. Triticale is thus a useful rotational crop for areas infested with the root lesion nematode. [95]

1.9.1 Nematode testing of soil

PreDicta B

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.

PreDicta B includes tests for:

- Cereal cyst nematode (*Heterodera avenae*).
- Root lesion nematode (*Pratylenchus neglectus and P. thornei*).
- Stem nematode (*Ditylenchus dipsaci*).

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.

PreDicta B samples are processed weekly between February to mid-May (prior to crops being sown) every year.

PreDicta B is not intended for in-crop diagnosis. See the crop diagnostic webpage for other services. [96]

95 Vanstone, V., Farsi, M., Rathjen, T., & Cooper, K. (1996). Resistance of triticale to root lesion nematode in South Australia. In *Triticale: Today and Tomorrow* (pp. 557–560). Springer Netherlands.

96 PIR.SA, SARDI. 2016. PreDicta B. http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

MORE INFORMATION

[Tips and tactics: Root-lesion nematodes, Western region.]

1.9.2 Effects of cropping history on nematode status

Well-managed rotations are vital. Avoid consecutive host crops to limit populations. Choose varieties with high tolerance ratings to maximise yields in fields where root-lesion nematode (RLN) is present. Choose rotation crops with high resistance ratings, so that fewer nematodes remain in the soil to infect subsequent crops.

For more information, see Section 8: Nematode control

1.10 Insect status of paddock

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 compliment chemical and biological controls. [97]

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

Soil insects include:

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

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

- Weedy fallows and volunteer crops encourage soil insect build-up.
- Insect numbers decline during a clean long fallow due to lack of food.
- Summer cereals followed by volunteer winter crops promote the build-up of earwigs and crickets.
- High levels of stubble on the soil surface can promote some soil insects due to a food source, but this can also mean that pests continue feeding on the stubble instead of germinating crops.
- No-tillage encourages beneficial predatory insects and earthworms.
- Incorporating stubble promotes black field earwig populations.
- False wireworms are found under all intensities of cultivation but numbers decline if stubble levels are very low.

Soil insect control measures are normally applied at sowing. Since different insects require different control measures, the species of soil insects must be identified before planting. Soil insects are often difficult to detect as they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the moist/dry soil interface.

97 https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests

1.10.1 Insect sampling of soil

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.

The majority of crop monitoring for insect pests is done with a sweep net, or visually. Using a shake/beating tray is another technique. Sampling pastures mostly relies on visual assessment of the sward or the soil below it. The sweep net is the most convenient sampling technique for many insects. The net should be about 38 cm in diameter, and swept in a 180° arc from one side of the sweepers body to the other. The net should pass through the crop on such an angle that it is tilted so that the lower lip travels through the crop marginally before the upper lip. The standard sample is 10 sweeps, taken over 10 paces. This sampling 'set' should be repeated as many times as practicable across the crop, and at no less than 5 locations. After completing the sets of sweeps, counts should be averaged to give an overall estimate of abundance. Sweep nets tend to under-estimate the size of the pest population. Sweep net efficiency is significantly affected by temperature, relative humidity, crop height, wind speed, plant density and the operator's vigour. [98]

Soil sampling by spade

1. Take a number of spade samples from random locations across the field.
2. Check that all spade samples are deep enough to take in the moist soil layer (this is essential).
3. Hand-sort samples to determine type and number of soil insects.

Germinating-seed bait technique

Immediately following planting rain:

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

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, use of the type of seed to be sown as a crop is likely to indicate the species of pests that could damage that crop. The major disadvantage of the germinating-grain bait method is the delay between the seed placement and assessment. [99]

The South Australian Research and Development Institute (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. [100]

98 http://ipmguidelinesforgrains.com.au/insectopedia/introduction/sampling.htm

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

100 http://pir.sa.gov.au/research/research_specialties/sustainable_systems/entomology/insect_diagnostic_service

Insect ID: The Ute Guide

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. [101]

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.

See Section 7: Insect control for more information or visit the Pest Genie Australia or APVMA.

1.10.2 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. [102] 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. [103]

See Section 7: Insect control for more information.

101 https://grdc.com.au/Resources/Apps

102 https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers

103 https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests

Pre-planting

Key messages

- Triticale breeding programs have produced a number of new varieties designed for particular uses and regions.
- Breeding programs have aimed at improving grain yield and dry matter production. This has produced winter triticales with a wider range of sowing dates, improved grazing habit (having the growing point closer to the ground), and new sources of rust resistance.
- Triticale is extensively used in dual-purpose cropping systems, with specifically bred varieties.
- Ensure that seed quality is of a high standard. Check for damage and discolouration as affected seeds may have poor germination and emergence.
- The larger seed size of triticale means that emergence is consistently good, as long as seed is of high quality.
- Consult local variety sowing guides for the best practices for your region.

There are two types of triticale to choose from—grain only and dual purpose (Photo 1). Grain only varieties perform best in long-season environments rather than lower rainfall regions with unreliable springs. Dual purpose varieties can be sown very early, grazed during winter then shut up for forage conservation or grain recovery. [1]

Photo 1: *Triticale combines the high yield potential and good grain quality of wheat with the disease and environmental tolerance (including soil conditions) of rye.*

Source: SeedTech

1 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

IN FOCUS

Triticale testing, Northam WA.

In 2006, triticale trials were conducted in Northam, WA (Table 1 and 2). [2]

Table 1: *Triticale trial details, Northam, WA 2006.*

Soil group	Soil pH ($CaCl_2$) 6.1 at 10 cm and 4.2 at 30 cm.
Sowing date	28/06/06
Seeding rate	76 kg/ha
Rotation	2005: Medic and grass pasture, 2004: Wheat. 2003: Medic and grass pasture.
Fertiliser (kg/ha)	28/06/06: Agras #1 80 kg/ha 28/06/06: Treflan 1.6 L/ha; Sprayseed 1.6 L/ha
Pesticides	15/09/06: Dominex 200 mL/ha 26/09/06: Wipeout 450 1.6 L/ha

Source: DAFWA and Liebe Group

Table 2: *Results of triticale trials, Northam, WA, 2006.*

Variety	Yield (kg/ha)	% of Tahara	Growth scores	% of Tahara
Tickit	612	121*	5.0	116
Everest	524	104	4.3	100
Prime-322	520	103	5.0	116
Credit	507	100	5.0	116
Speedee	507	100	5.3	123
Tahara	505	100	4.3	100
Muir	465	92	5.0	116
Mean	514	-	5	-
Av. SED	37	-	-	-
CV	8.8	-	16.8	-

* = Significant (0.05). Adjusted yield data. Obs dates: 21/11/06. Growth Scores: 5/09/06
Source: DAFWA and Liebe Group

2.1.1 Triticale as a dual-purpose crop

Key points:

- Advantages of dual purpose crops include minimising risks, capitalising on early rainfall events, flexibility in enterprise mix, and improved cash-flow
- Dual purpose crops require a high standard of management
- Ideal grazing facilities would allow for an excellent water supply, shelter belts, rotational grazing, and drafting cattle into similar weight ranges before being

2 Garlinge J (2006). Triticale testing- Stage 3. DAFWA, Liebe Group. http://www.farmtrials.com.au/trial/10443

placed onto grazing crops. Try to minimise handling and ensure that all animal health issues are addressed. [3]

- When a dual-purpose triticale is grown with the intention of providing winter grazing and then optimising grain production the time of stock removal or lock-up is important.

Dual-purpose crops hold great potential to utilise early-season sowing opportunities to provide extra grazing for livestock and maintain grain yield. With good management, the period of grazing can increase net crop returns by up to $600/ha and have a range of system benefits including widening sowing windows, reducing crop height, filling critical feed gaps and spelling pastures. Over ten years of experiments, simulation studies and collaborative on-farm validation across Australia has demonstrated that a wide range of cereal and canola varieties can be successfully grazed and recover to produce combined livestock and crop gross margins that exceed grain-only crops, and increase whole-farm profitability. [4]

The Australian dual-purpose cereal crop (including triticale, wheat, oats, barley and cereal rye) is increasing in importance because of factors such as higher-value animal industries. The ability of several recent variety releases to provide valuable winter grazing, as well as a grain yield similar to grain-only crops, helps farmers to improve winter feed supply after pastures have been affected by drought. [5]

Dual purpose cropping in WA

Increasingly in WA, paddocks are earmarked for grazing and are sown earlier to provide early plant growth - knowing that grazing will retard maturity - and spread frost risk. Research is finding that there is a high correlation between total crop biomass at harvest and yield. The best yield results are from crops with the greatest total crop biomass at harvest. The implication is that the best crop biomass recovery comes from grazing heavily for short intervals early, or leaving more residual after later grazing. More severe grazing (e.g. higher stocking rates for longer), which may have some yield impact, is better in severe frost-prone areas. In a dry year, dual purpose crops can provide an important 'fall back' position for winter dry matter production, allow pastures to get away and reduce costly supplementary feeding for livestock enterprises. In dry years and in years when grain prices are high, the economics of the amount of grazing value provided by the crop needs to be weighed-up against the impact on returns of even a small yield penalty from grazing the crop outside the preferred window. This impact must be tempered by the value the grazing has had to the livestock system. Benefits to the livestock enterprise may include improved animal performance, young animals able to be finished prior to sale, stock to be retained rather than forced to be sold, increased lamb survival and reduced ewe mortalities. [6]

Benefits of growing dual purpose or winter forage crops

1. *Minimises risks*

- Floods close to grain harvest have caused or can cause severe damage to ripening crops
- Floods during the growing period of grazing crops can provide irrigation-type benefits
- Floods in November/December on grazing crops are not so critical as benefits are already banked
- Minimises the risks associated with dry periods late winter/spring such as 2013/2014/2015.

3 Harris K. (2016). GRDC Update Papers: Dual purpose crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/dual-purpose-crops

4 Kirkegaard J, Sprague S, Lilley J, Bell L. (2016). GRDC Update Papers: Managing dual purpose crops to optimise profit from grazing and grain yield north. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Managing-dual-purpose-crops-to-optimise-profit-from-grazing-and-grain-yield-north

5 GRDC Ground Cover Issue 66 – Jan-Feb 2007. Dual-purpose crops: Adaptable triticale steps up. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-66-January-February-2007/Dualpurpose-crops-Adaptable-triticale-steps-up

6 GRDC. (2014). Grazing dual purpose crops in Western Australia. https://grdc.com.au/Media-Centre/Hot-Topics/Grazing-dual-purpose-crops-in-Western-Australia

2. Capitalises on early rainfall events

- Grazing or dual-purpose crops can be planted in late February & late March thus capitalising on late summer rainfall events. It also spreads workloads!
- Early sown crops will provide quality feed from mid-May most seasons.

3. Flexibility in Enterprise Mix

- It isn't totally reliant on grain prices/export markets/grain quality issues/ downgrading weather damage etc.
- Buying and selling trading cattle - there are budget profits from weight gains
- There is the opportunity to background cattle for feedlots and the potential to lock in sale price at purchase
- In most cases cattle prices at feedlots are higher when grain prices are down. Grain is a major input cost for feedlots and therefore it has a major impact on feedlot margins
- The decision to lock up dual-purpose crops does not need to be made until late July. During a normal average season when late winter/early spring feed reserves (pastures) are looking good dual-purpose crops can be locked up/top dressed/weed controlled if necessary and kept for grain production.
- Growers could also elect to continue to graze their crop, taking into account cattle & grain prices/stored soil moisture levels/seasonal outlook etc.

4. Improved cash-flow

- Dual purpose crops offer the benefit to generate early income from the start of the grazing period. Cattle are often sold after 70 days of grazing in late July and after achieving a weight gain of between 90–120 kg/head (budget 70 days x average 1.6 kg/head/day for a good crop).
- Remember you don't need to finish the cattle, best returns are often obtained from backgrounding cattle for local feedlots. A good idea is to speak with the feedlot before you buy the cattle, or there may be an opportunity to background cattle on their behalf, being paid for the weight gain only.
- A well-managed forage crop can provide sufficient early season feed for up to 5 weaners/ha. Therefore early income potential paid in August should realise well over $1,000/Ha.
- No need to wait until December or January (6–8 months) to realise cash-flow
- Dual-purpose crops grain recovery in northern areas should budget 50% of un-grazed crops. [7]

When to graze

Dual purpose varieties can be sown early for winter grazing (30–90 grazing days) and can then be locked up at spring time. The ideal grazing time is when the canopy is closed (GS21 – GS29) using a continuous grazing system. Do not graze below 5 cm with prostrate varieties and below 10 cm for erect varieties (Photo 2). [8]

The crop must be monitored regularly (at least twice each week) for stem elongation and the appearance of the first node.

This indicates the plant has gone into reproductive mode and grazing from this time onwards will reduce grain yield. Once the crop reaches this stage grazing should cease. [9]

MORE INFORMATION

Dual-purpose crops Factsheet

Optimising grazing and grain yield in dual-purpose crops

Dual purpose crops; do they have a fit in your system and how can they be managed to optimise forage and grain production

7 Harris K. (2016). GRDC Update Papers: Dual purpose crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/dual-purpose-crops

8 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

9 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

Photo 2: *Triticale grazed by cattle and used to clean up a paddock.*

Source: EverGraze

The ideal stage to start grazing dual-purpose varieties is when plants are well anchored and the canopy has closed. Continuous grazing is better than rotational grazing for fattening stock. Maintain adequate plant material to give continuous and quick regrowth of the crop (1000–1500 kg DM/ha).

The higher grazing height is particularly important with the erect-growing varieties. Over-grazing greatly reduces the plant's ability to recover. [10]

In southern trials, grain yields were generally reduced by grazing, possibly because the latest "grazing" occurred at or about GS31. This is likely to have resulted in the removal of the growing point of the primary tiller, resulting in fewer productive heads. Varieties that produced the highest grain yield when not grazed actually had the greatest yield loss when grazed. Protein content was reduced by grazing in all cereals while 1000 grain weight was reduced by grazing in triticale and wheat.

So long as farmers graze their cereals before they get to GS30-31 they can get a reasonable amount of grazing from that cereal. Once you get past that stage you are likely to have an impact on grain yield in the end. It is a matter of farmers trying to get some grazing in winter (when dedicated pastures are growing slowly and under pressure due to low dry matter levels) and then removing the stock to harvest a reasonable grain yield. [11]

When to use crop grazing in WA

The timing of the autumn break will heavily influence if and how soon crops can be used for livestock feed in the autumn-winter.

In most years in many grain growing areas of the State, there will be an opportunistic storm or rainfall event in autumn that will allow sowing of some dual purpose crops in March or April.

Grazing crops early, at about four weeks after sowing and for a short period of about 10 days, seems to have the least impact on plant growth and provide the best yield potential in low rainfall southern grain growing areas.

With longer grazing periods, the plant's ability to recover is more limited and yield potential is reduced, especially in low rainfall areas.

To allow an extended crop grazing period, a number of paddocks can be grazed for short periods in a series - minimising the impact in any one paddock, but providing a justifiable benefit to the farming system. [12]

MORE INFORMATION

Grazing dual purpose crops in Western Australia

Effect of cutting on early sown Triticale and Wheat

10 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

11 Roberts M. (2013). YP and Mid-north trials highlight benefits of grain and graze. http://www.grainandgraze3.com.au/resources/343_YPandMidNorthtrialshighlightbenefitsofGG.pdf

12 GRDC. (2014). Grazing dual purpose crops in Western Australia. https://grdc.com.au/Media-Centre/Hot-Topics/Grazing-dual-purpose-crops-in-Western-Australia

Trials have found that of four commonly used cereal cover crops (triticale, oats, wheat and barley), triticale produced the highest grain yield following grazing. [13]

IN FOCUS

Evaluation of triticale as dual-purpose forage and grain crops

Two cultivars of triticale, Tiga and Empat, were compared with existing commercial cultivars of triticale, cereal rye and forage oats, for grain yield and dry matter production. Their performance was evaluated in New South Wales, over 3 years with varying defoliation regimes (uncut to grain yield, cut in late autumn, cut in autumn and winter, and cut in winter only). Grain yields (up to 4.0 t/ha) of the highest yielding triticale cultivar (Empat) were equal to, or greater than, the best oats cultivar (Blackbutt). Generally, the highest winter growth rates, dry matter yield at maturity and grain yield were recorded from uncut plots. Cutting only in autumn had small effects (negative) on grain yields, but cutting in both autumn and winter reduced total dry matter yields at maturity by 30% and grain yields by 50%. Cutting only in winter resulted in higher vegetative forage yields than a double cut (autumn and winter), but the single winter cut subsequently produced lowest dry matter yields at maturity. The high grain yields of triticale were linked to rapid spring growth. Harvest indices of triticale cultivars were generally lower than those of the oat cultivars. The results indicate the potential of triticale, especially cv. Empat, as a dual-purpose forage and grain crop. [14]

Breeding dual-purpose Triticale

Grain producers have expressed the importance to of dual-purpose triticale varieties, as they want to graze the crop through autumn and winter, and have a subsequent grain crop, thus increasing the gross margin per hectare and also providing an insurance against harvest failure. Grazing cereals produce two times the amount of dry matter compared to pastures during the autumn and winter, and also allow pastures to be rested over the winter thus allowing for better production in the spring.

Triticale is advantageous in some areas due to its tolerance of acid soils and high exchangeable aluminium present in these soils, especially where the sub-soil is acid and cannot be easily corrected by liming.

With support from the GRDC, the University of Sydney aims to improve the productivity of dual-purpose triticales through plant breeding. Breeding programs have aimed at improving grain yield and dry matter production. This has produced winter triticales with a wider range of sowing dates, improved grazing habit (having the growing point closer to the ground), and new sources of rust resistance. Shorter triticales have also been produced to reduce the amount of stubble after harvest, suiting conservation tillage farming practices, and also to improve grain yield.

Hybrid triticale is also under development to increase yield by exploiting heterosis, the superiority of the F1 hybrid over the highest yielding inbred varieties.

The breeding program addresses grain quality aspects of triticale in relation to the animal industries, with the aim of improving animal productivity when fed triticale. This

13 Serafin L, Gardner M, Fleming J, Pottie D, Harden S. (2013). Dual purpose cereals: varieties and management for the northern slopes and plains. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Dual-Purpose-Cereals-Varieties-and-Management-for-the-Northern-Slopes-and-Plains

14 Andrews, A. C., Wright, R., Simpson, P. G., Jessop, R., Reeves, S., & Wheeler, J. (1991). Evaluation of new cultivars of triticale as dual-purpose forage and grain crops. *Animal Production Science*, *31*(6), 769–775.

MORE INFORMATION

Dual-purpose Triticale Improvement program

Triticale: grazing guide

program concentrates on grain characteristics for ruminants (grain quality for pigs being covered by the Pork CRC).

This program provides benefits to the grains industry through the identification of dual-purpose triticales with improved productivity. [15]

2.1.2 Triticale grain for livestock

The major uses for triticale grain are as a feed supplement in the dairy industry, as a component ingredient in beef feedlots and as a constituent of compound rations for intensive livestock (pigs and poultry) rations. In livestock diets, triticale has a similar role to other cereals (Tables 3 and 4). It is primarily an energy source having moderate protein content with high starch and other carbohydrates, giving it high energy content.

A key physical feature of triticale is that it is a soft grain with a hardness index almost half that observed for wheat and barley. This is an advantage as less mechanical energy is required to mill triticale compared to wheat and barley prior to inclusion in livestock diets.

On farm, triticale can be fed to livestock in the same way wheat or barley would be fed. [16]

Triticale is well suited to feeding dairy cows (Table 5).

Table 3: *Crude protein concentration and yield and percent digestible dry matter IVDDM and yield of four small grain species harvested at the milk stage of maturity.* [17]

Species	Crude protein		IVDDM	
	%	T/A	%	T/A
Spring wheat	15.7	0.43	63.3	1.72
Triticale	15.2	0.45	66.4	1.95
Oat	14.6	0.44	61.5	1.86
Barley	15.7	0.50	68.5	2.20

Source: Cherney and Marten, 1982

15 University of Sydney. (2012). Triticale.

16 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

17 Cherney and Marten, 1982, University of Minnesota and USDA in https://www.hort.purdue.edu/newcrop/afcm/triticale.html

Table 4: *Forage and diet composition (dry matter basis).* [18]

Item	Alfalfa	Triticale	Oat
	%		
Forage			
Dry matter	43.5	37.8	28.0
Crude protein	22.6	17.5	142.0
Neutral detergent fibre	43.8	54.8	52.4
Acid detergent fibre	32.9	32.1	31.1
Calcium	1.69	.56	.42
Phosphorus	.43	.56	.39
Diet			
Dry matter	58.1	52.4	43.7
Crude protein	16.4	17.2	17.3
Neutral detergent fibre	30.3	36.9	36.0
Acid detergent fibre	18.0	19.8	19.3

Source: Cherney and Marten, 1982

Table 5: *Effect of forage on milk yield and milk composition.* [19]

Item	Forage source		
	Alfalfa	Triticale	Oat
No. of cows	15	15	12
Milk yield and composition			
3.5% FCM 2 (lb/cow/day)	64.7ab	71.9a	60.7b
fat, %	3.7	3.7	3.9
protein, %	3.4	3.4	3.4
total solids, %	13.3	13.3	13.4

FCM = Fat-corrected milk.
ab = Means differ (P .05).
Source: Cherney and Marten, 1982

MORE INFORMATION

Triticale: stock feed guide

A guide to the use of Triticale in livestock feeds

Protein content of triticale is thought to depend most on the cultivar, less on the weather conditions of the growth year and least on nitrogen fertiliser application. [20]

2.1.3 Triticale as a cover crop

A cover crop is a crop planted primarily to manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity and wildlife in an agroecosystem. One approach used in southern cropping regions involves annual crops being sown into lucerne, a practice known as *lucerne inter-cropping* (Figure 1). The benefits of sowing annual crops into established Lucerne include reducing the risk of rainfall leakage during the cropping phase, as well as eliminating the costs of Lucerne removal and re-establishment.

Triticale has poor tillering capacity and good tolerance to shattering. This makes triticale a useful cereal as a cover crop to establish undersown lucerne or medic, but

18 Paulson, Ehle, Otterby, and Linn, 1987, University of Minnesota in https://www.hort.purdue.edu/newcrop/afcm/triticale.html

19 Paulson, Ehle, Otterby, and Linn, 1987, University of Minnesota in https://www.hort.purdue.edu/newcrop/afcm/triticale.html

20 Alaru, M., Laur, Ü., & Jaama, E. (2003). Influence of nitrogen and weather conditions on the grain quality of winter triticale. *Agronomy Research*, *1*(1), 3–10.

seeding rates may need to be reduced [21] e.g. reduce seeding rate to approximately 10 to 20% of normal, targeting 15—30 plants per m^2. [22]

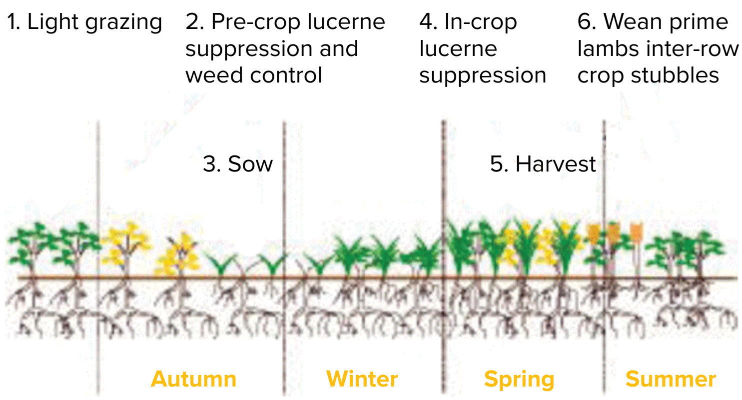

Figure 1: *Lucerne inter-cropping practice.*

Source: AgVic

Use grain only varieties that are early maturing and choose a paddock with a low weed seed bank because of limited options for herbicides with varying species.

Under-sowing lucerne

Triticale has been used to under-sow perennial pasture, in particular lucerne (Photo 3). When under-sowing:

- Use a grain only variety with the earliest available maturity suited to your region
- Sow the triticale at lower seeding rate than used for optimising grain yield
- Choose a paddock with low weed numbers as the combination of species can dramatically reduce herbicide options
- Expect a reduction in grain yield. [23]

Photo 3: *A paddock of cereal under sown with lucerne.*

Source: Andy Howard

As far as amount of growth triticale is very similar to that of a cereal rye plant, growing three to five feet in height. It also has an excellent fibrous root system that makes it an excellent choice for preventing erosion, scavenging for nutrients, and also building soil structure.

MORE INFORMATION

Farmers' experience with Lucerne inter-cropping

21 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

22 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

23 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

MORE INFORMATION

Break crop benefits to wheat crops in Western Australia

Break crop – WA's frontline weapon for weeds

Astute⟃ - AGT

Berkshire⟃ brings home the bacon

Triticale has excellent grazing and forage values. It has a heavy residue on the surface much like that of cereal rye if allowed to reach maturity, thus also making it a good choice for weed suppression. [24]

Triticale is a hardy cover crop that can suppress weeds and produce a moderate to high amount of biomass. Triticale will not produce as much biomass as rye, and may not tie up as much N in the spring.

Triticale is thought to be able reduce soil compaction, loosen topsoil and remove excess soil moisture. [25]

2.2 Varietal performance and ratings yield

New varieties

Astute⟃ is a new mid-season triticale that is an alternative to Hawkeye⟃. Bison⟃, first listed in 2015 and were available in 2016.

New Astute⟃

A mid season fully-awned variety suited to medium-high yielding environments and alternative to Hawkeye⟃. Stem rust RMR, stripe rust RMR# and leaf rust RMR. Bred by AGT (as TSA0466) and registered 2015. Astute⟃ (TSA0466) was bred with the aim of producing a very high yielding triticale which would be the choice for growers looking to maximise the production from their triticale crops in high potential environments. Astute⟃ combines broad adaptation, resistance to rust and CCN, good physical grain quality and top-end yield capabilities.

Astute⟃ is suited to high yield potential areas of NSW and Victoria, with a very similar flowering time to Hawkeye⟃ and Fusion⟃. Astute⟃ is a fully awned triticale with excellent agronomic characteristics for grain production.

Berkshire⟃

A mid-season awned variety with good straw strength. Stem rust R, stripe rust MRMS# and leaf rust R. Has been purpose bred for high yield and feed quality traits for pigs by the University of Sydney and Pork CRC, registered 2009.

- Improved ileal digestible energy—13 MJ/kg compared to Tahara at 12 MJ/kg
- Reduced fibre content—5 to 10% less than Tahara
- Excellent yield—equivalent to best grain only varieties currently available
- Good straw strength
- Quick to mid-season maturity
- Moderately resistant to WA and Jackie strains of stripe rust [26]

New Bison⟃

An early to mid season reduced awn variety best suited to low-medium yielding environments. Intended as a replacement for Rufus. Stem rust RMR, stripe rust R# and leaf rust RMR. It has a reduced awn, and is early to mid-season maturity.

- Early-mid maturing, feed quality triticale
- Tall plant type with reduced awns and excellent disease package
- Resistant to stem rust and stripe rust, and resistant-moderately resistant to leaf rust
- Resistant to CCN, moderately resistant to YLS, and resistant-moderately resistant to septoria tritici blotch
- Tolerant to acid soils

24 Advance cover crops – Triticale. http://www.advancecovercrops.com/portfolio_item/triticale/

25 NCRS. (2011). Cover crop – Planting specification guide. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1081555.pdf

26 Waratah Seed Co Ltd. (2011). Triticale: Variety guide. http://www.waratahseeds.com.au/content/Triticale-guide-varieties.pdf

MORE INFORMATION

Bogong⚫ and Fusion⚫ – inseperable in 2014 trials

Bogong⚫ and Canobolas⚫ SA/Vic/NSW

Chopper⚫ - AGT

Fusion⚫ - GRDC

Goanna triticale

PODCAST

LISTEN: Ground Cover Radio 110: Triticale program further lifts crop productivity.

Bogong⚫

Bogong⚫ (tested as H127) was released by the University of New England, Armidale, in 2008. It is a grain variety with early to mid-season flowering (similar to Treat). It is fully awned, stiff strawed and has good resistance to all common field strains of rust. Bogong⚫ has been one of the top yielding varieties over the past seven seasons (up to 15% above Tahara) of evaluation across all environments. It is a widely adapted spring variety that is moderately susceptible to CCN. [27]

Canobolas⚫

Early to mid-season awned variety with stiff straw, shorter than Tahara. A widely adapted spring variety with acid soil tolerance. Stem rust R, stripe rust MRMS# and leaf rust RMR. Bred by the University of New England, registered 2009.

Chopper⚫

An early maturing, awned semi dwarf variety which resists lodging in high yielding environments. Has good grain quality and performs best in short growing seasons or late sowing situations. Stem rust MR, MRMS# to stripe rust and leaf rust R. Released in 2010.

Chopper⚫ is a fully awned spring triticale, that is very early maturing (3–4 days earlier than Speedee, 7–15 days earlier than Tahara). Chopper⚫ is a semi-dwarf, making it significantly shorter than all other currently available triticale varieties (15% shorter than Tahara). Therefore, Chopper⚫ will not lodge to the extent of commonly grown tall or moderately tall triticale varieties.

Fusion⚫

A mid-season variety (similar to Tahara), fully awned grain only triticale. A moderately tall variety that yields well in dry or sudden finishes. Stem rust R, stripe rust RMR#, leaf rust R and resistant to CCN. Released in 2012. Fusion⚫ produces large grain with low screening losses. Hectolitre weight is similar to that of Hawkeye⚫ and Jaywick⚫, the benchmark varieties for this quality attribute. Fusion⚫ is a mid-season maturity, spring-habit variety. Its desirable sowing time is similar to Hawkeye⚫ and Tahara. Fusion⚫ is a fully awned triticale variety. It has moderate plant height, slightly taller than Hawkeye⚫ and Jaywick⚫, and similar height to Rufus.

Goanna

An early to mid-season, fully awned grain only triticale. Stem rust R, stripe rust RMR#, leaf rust R and resistant to CCN. Released in 2011. Goanna is an early-medium season (similar heading time to Treat, Tickit, Rufusand Hawkeye⚫), spring type, grain triticale, which has good resistance to current pathotypes of stem, leaf and stripe rusts (2010 season) plus full resistance to cereal cyst nematode. Goanna is a fully-awned, tall, white-chaffed variety, which is appearing for the first time in the National Variety Trials, in 2011.

KM10

A fast growing early to mid season variety with good early production of forage. Tends to smaller grain and is ideally suited to short season environments. Stem rust R, stripe rust R#, leaf rust MRMS but susceptible to CCN. Released in 2014. It is very quick growing and is a reduced awn head type with excellent early forage production in all rainfall zones. Although tending to have reduced grain size, KM10 is particularly suited to grain production in shorter season areas.

Tahara

A variety that has been widely grown for many years because of its reliability across a range of environments, but now outclassed by newer options. It may lodge in high yielding situations. Stem rust R, stripe rust MRMS#, leaf rust R and resistant to CCN.

27 Jeisman C. (2015). Triticale variety sowing guide 2015.

Suited to most districts with rainfall up to 550 mm. Released 1987 by the Victorian Department of Agriculture.

Tahara has long been the benchmark variety for use in cereal rotations in most districts up to 500 mm average annual rainfall however its tall plant height makes it prone to lodging under high yielding situations.

Tahara has good resistance to CCN and root lesion nematode (*Pratylenchus neglectus*) making it a valuable disease break option.

Tahara is moderately susceptible to stripe rust however and outclassed for yield by many newer grain varieties. Tahara seed can be purchased from commercial growers.

Yowie

A medium to tall mid-season grain variety that is fully awned and white-chaffed. Stem rust R, stripe rust MR#, leaf rust R and resistant to CCN. Released in 2010.

Yowie is a medium season (slightly later heading than Tahara), spring type, grain triticale, which has good resistance to current pathotypes of stem, leaf and stripe rusts (2010 season) plus full resistance to cereal cyst nematode.

Yowie is a fully-awned, medium-tall, white-chaffed variety, of similar yield performance to other triticale varieties in the National Variety Trials, in which it appeared for the first time in 2010. Test weights were relatively good and screening levels relatively low.

MORE INFORMATION

Yowie triticale

Endeavour⍉ triticale

Hawkeye⍉

Hawkeye⍉ (tested as TSA0108) was released by AGT in 2007 and is a broadly adapted, mid maturing variety with high yield potential and CCN resistance. It has good resistance to all rusts and produces large grain with low screenings (similar to Tahara) and good test weight (like Treat). It is considered a high yielding alternative to Tahara and a CCN and stripe rust resistant alternative to Kosciuszko.

Jaywick⍉

Jaywick⍉ (tested as TSA0124) was released by AGT in 2007 and is a broadly adapted, mid maturing variety with high yield potential and CCN resistance. It has moderate to good resistance to all rusts and produces large grain with low screenings and good test weight. It is considered a slightly earlier, higher yielding alternative to Tahara.

2.2.1 Dual-purpose triticale

These varieties can be grazed early and then allowed to produce grain or cut for hay.

Endeavour⍉

Long season variety with similar maturity to Breakwell⍉. Semi-awnless with excellent dry matter production and grain recovery after grazing. Stem rust R, stripe rust RMR#, leaf rust R. Registered 2008.

- Resistant to current strains of stripe rust at both seedling and adult growth stages
- Excellent dry matter production
- High yield after grazing
- Good straw strength

Rufus

A mid-season maturing variety, with a tall growth habit and reduced awns which is favoured for hay production. Stem rust R, stripe rust MRMS#, leaf rust R and resistant to CCN. Grain yields in higher rainfall regions have been superior to Tahara but may also cause lodging. Released in 2005 by University of New England.

MORE INFORMATION

Tobruk⦇ triticale

Triticale trials

Tobruk⦇

With a strong winter habit Tobruk⦇ is a dual purpose or long season grain only variety with excellent grain yield. Stem rust R, stripe rust MR#, leaf rust R. Earlier flowering than Breakwell⦇ and Endeavour⦇. Released 2007.

- Seedling susceptible but adult plant resistant to the Jackie strain of stripe rust
- Strong winter habit
- Excellent yield after grazing compared to all other varieties in the NSW mixed cereal trials
- Easy threshing
- In some environments, it is affected by stripe rust head infection

Tuckerbox

Tuckerbox is a late-medium season, tall, high tillering variety with reduced awn head type, which may be grown for forage or grain. Stem rust MR, stripe rust MR#, leaf rust R. Released in 2009. Tuckerbox has good resistance to all rusts and CCN.

Yukuri

Yukuri was bred by the University of New England in 2004 and is a late-medium season variety with reduced awn head type. It is suitable for forage and grain production in environments with 450 mm+ rainfall. It has very good rust resistance, but is susceptible to CCN.

2.3 Planting seed quality

Before determining seed sowing rates, seed germination levels need to be known. For purchased seed this will be stated on the bags supplied. For home grown seed percentage germination can be simply estimated by moistening the seed in blotting paper on a saucer covered by another inverted saucer. The seed should be kept warm (20°C) and moist for 10 days and after that period, the percentage germination can then be recorded. Seed with approximately 90 per cent germination or more is suitable for sowing. Seed produced in tableland cooler environments may tend to have poorer germination levels than seed produced in warmer regions; hence the need to check the germination rate. [28]

Heat damage in seeds 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.

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

Source: Grain SA

28 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

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

With dramatic increases in herbicide resistance, growers need to take seed purity into account when selecting paddocks for seed. Ryegrass and black oats frequently appear in harvested grain samples and have the potential to infest otherwise clean paddocks. [29]

2.3.1 Seed size

Seed size is an important physical indicator of seed quality that affects vegetative growth and is frequently related to yield, market grade factors and harvest efficiency. A wide array of different effects of seed size has been reported for seed germination, emergence and related agronomic aspects in many crop species. Generally, large seed has better field performance than small seed. Triticale has the largest seed size of all common small-grained cereal crops (Photo 5).

With increased seed size, higher germination and emergence has been noted in triticale. Large seeds show a higher emergence potential than smaller seeds. Larger seeds are capable of emerging from greater planting depths and showed an enhanced ability to penetrate ground cover and survive burial by litter. [30]

Photo 5: *Triticale seed (left) is much larger than wheat seed (right).*

Source: Alberta Ag

Early research found that Triticale plants from larger seed were superior in total germination, seedling dry weight, and in seedling establishment than those from small seed. Large seed of a given cultivar gave 51% higher field stand, 62% more seedling dry weight and 37.8% higher grain yield than plants from small seed. [31]

Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if seed is undamaged, stored correctly and from a plant that had adequate nutrition. Seed should not be kept from paddocks that were rain-affected at harvest. Seed grading is an effective way to separate good quality seed of uniform size from small or damaged seeds and other impurities, such as weed seeds. Seed size is also important—the larger the seed, the greater the endosperm and starch reserves (Photo 6). Although size does not alter germination, bigger seeds have faster seedling growth, a higher number of fertile tillers per plant and potentially higher grain yield.

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

30 S. Ambika, V. Manonmani and G. Somasundaram, 2014. Review on Effect of Seed Size on Seedling Vigour and Seed Yield. *Research Journal of Seed Science, 7: 31–38.*

31 Bishnoi, U. R., & Sapra, V. T. (1975). Effect of seed size on seedling growth and yield performances in hexaploid triticale. *Cereal Research Communications*, 49–60.

Photo 6: *Plants from small seeds have less vigour and lower yield (right).*

Source: DAFWA

Seed size is usually measured by weighing 1000 grains, known as the 1000-grain weight. Sowing rate needs to vary according to the 1000-grain weight for each variety, in each season, in order to achieve desired plant densities. [32]

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

The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface (Photo 7). Coleoptile length is an important characteristic to consider when planting a crop, especially in drier seasons when sowing deep to reach soil moisture.

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

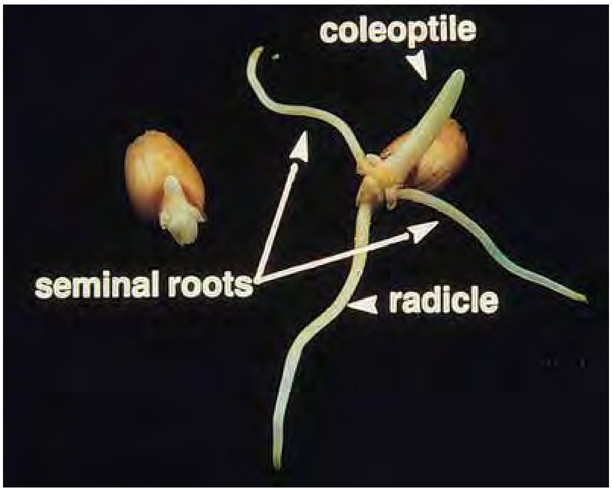

Photo 7: *The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface.*

Photo: David L. Hansen, University of Minnesota

For a seed to emerge successfully from the soil, the seed should never be planted deeper than the coleoptile length. Sowing varieties with short coleoptile lengths too deep can cause poor establishment, because the shoot will emerge from the coleoptile underground and it may never reach the soil surface. [33]

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. [34]

2.3.2 Seed germination and vigour

Seed germination and vigour greatly influence establishment and yield potential.

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

- water absorption (imbibition)
- activation
- visible germination[35]

Triticale has excellent vigour due to its hybrid characteristics. [36] Triticale germination increases with increasing seed size.

Seed vigour affects the level of activity and performance of the seed or seed lot during germination and seedling emergence. Loss of seed vigour is related to a reduction in the ability of the seeds to carry out all of the physiological functions that allow them to perform.

This process, called physiological ageing (or deterioration), starts before harvest and continues during harvest, processing and storage. It progressively reduces performance capabilities due to changes in cell membrane integrity, enzyme activity and protein synthesis. These biochemical changes can occur very quickly (a few days) or more slowly (years), depending on genetic, production and environmental

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

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

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

36 AGF Seeds. (2012). Triticale. https://agfseeds.com.au/triticale

factors not yet fully understood. The end point of this deterioration is death of the seed (i.e. complete loss of germination).

However, seeds lose vigour before they lose the ability to germinate. That is why seed lots that have similar, high germination values can differ in their physiological age (the extent of deterioration) and so differ in seed vigour and therefore the ability to perform. [37]

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

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. [38]

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.

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 (Photo 8). Ideally, the test should be done indoors at a temperature of ~20°C or lower.
- Alternatively, lay a well-rinsed plastic milk container on its side and cut a window in it, place unbleached paper towels or cotton wool in the container, and lay out the seeds. Moisten and place on a window-sill. Keep moist, and count the seeds as outlined below.
- Randomly count out 100 seeds, do not discard damaged ones, and sow 10 rows of 10 seeds at the correct seeding depth. This can be achieved by placing the seed on the smoothed soil surface and pushing in with a pencil marked to the required depth. Cover with a little more sand/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. [39]

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

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

39 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

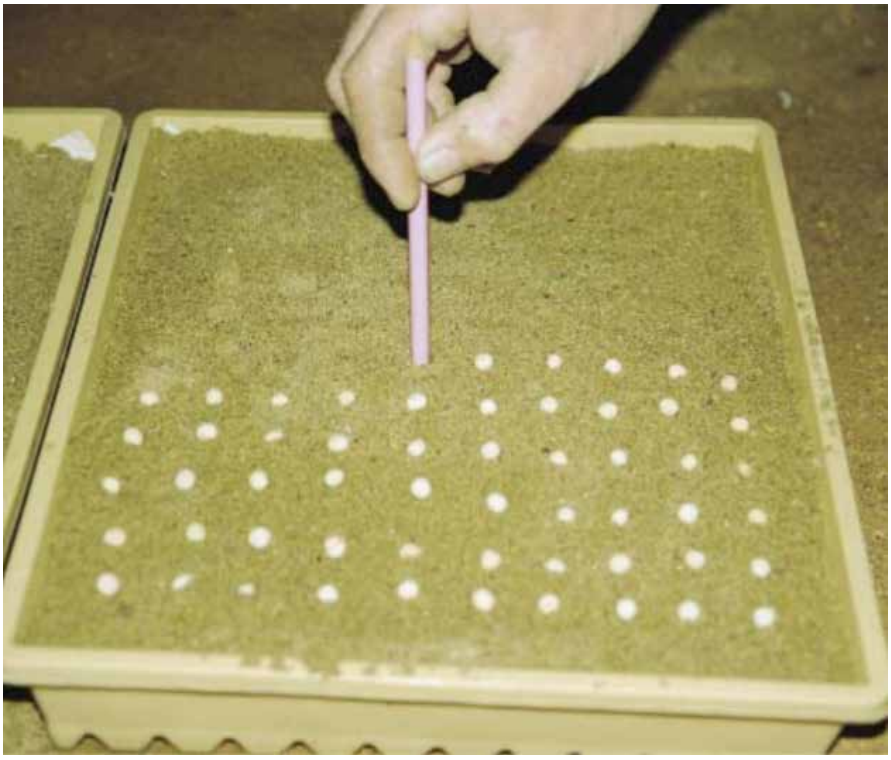

Photo 8: *Use a pencil or straw to poke holes in a testing tray.*

Source: NSW DPI

2.3.3 Seed storage

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

Triticale is a softer grain than wheat and barley, which may make it easier to mill for livestock diets, but may cause it to be more susceptible to insect damage in long term storage. [40]

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 is so important.
- Moisture control. Temperature changes cause air movements inside the silo, carrying moisture to the coolest parts of the seed. Moisture is carried upwards by convection currents in the air; these are created by the temperature difference between the warm seed in the centre of the silo and the cool silo walls, or *vice versa*. Moisture carried into the silo 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.
- No pests. Temperature <15°C stops all major grain insect pests from breeding, slowing down their activity and causing less damage. [41]

For more information, see Section 13: Storage.

MORE INFORMATION

Germination testing and seed rate calculation

VIDEOS

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

40 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

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

2.3.4 Safe rates of fertiliser sown with the seed

A productive triticale will require application of phosphorous (P) and nitrogen (N) at sowing. Additional nitrogen is likely to be required for maximum dry matter production for grazing and grain yield, particularly if the crop has been grazed.

Consider applying 15—20 kg P per ha at sowing. This is equivalent to 75—100 kg MAP per ha which will also include 7.5—10 kg N per ha. A triticale used for grazing as well as grain production will require significant N. [42]

As with most crops, rates of fertiliser application should be based on soil testing and other historical response information as well as anticipated costs and returns.

Crop species differ in tolerance to N fertiliser when applied with the seed at sowing. Research work funded by Incitec Pivot Fertilisers has shown that the tolerance of crop species to ammonium fertilisers placed with the seed at sowing is related to the fertiliser product (ammonia potential and osmotic potential), the application rate, row spacing and equipment used (such as a disc or tine), and soil characteristics such as moisture content and texture.

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. 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 (Tables 6 and 7). [43]

Nitrogen 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.

Table 6: *Approximate safe rates of nitrogen as urea, mono-ammonium phosphate (MAP) or diammonium phosphate (DAP) with the seed of cereal grains if the seedbed has good soil moisture (at or near field capacity).* [44]

	25 mm (1”) seed spread			50 mm (2”) seed spread		
Soil texture	Row Spacing			Row Spacing		
	180 mm (7”)	229 mm (9”)	305 mm (12”)	180 mm (7”)	229 mm (9”)	305 mm (12”)
		SBU			SBU	
	14%	11%	8%	29%	22%	17%
Light (sandy loam)	20	15	11	40	30	22
Medium-heavy (loam to clay)	25	20	15	50	40	30

42 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

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

44 Farmer Community (2014) Guidelines for suggested maximum rates of fertiliser applied with the seed in winter crops. Fertiliser Facts. Incitec Pivot Ltd, http://farmercommunity.incitecpivotfertilisers.com.au/

Table 7: *Urea rates for cereals on different soil types.* [45]

Crop:	**Wheat, barley**							
Product:	**Urea (46% nitrogen)**							
Soil Moisture : Good								
SBU %	5	10	15	20	25	30	40	50
					Kg/ha			
Heavy Soil	55	60	65	70	75	80	95	105
Medium Soil	45	50	55	60	65	70	80	90
Light Soil	25	30	35	40	45	50	60	65

Seedbed utilization (SBU)% = (width of seed row/row spacing) x 100. Contact your agronomist or fertiliser supplier for other details on other blends.

For more information, see Section 5: Nutrition and Fertiliser.

45 Farmer Community (2014) Guidelines for suggested maximum rates of fertiliser applied with the seed in winter crops. Fertiliser Facts. Incitec Pivot Ltd, http://farmercommunity.incitecpivotfertilisers.com.au/

Planting

Key messages:

- Triticale is not usually prone to infection from smuts and bunt. However, it is good insurance to apply a seed dressing to the grain when it is being graded.
- Triticale generally has a similar sowing time requirement to other cereals and should take a priority in the sowing schedule commensurate with its importance to the overall cropping enterprise. Triticale often suffers more from frost damage than wheat, hence it should generally be sown later.
- Aim to achieve the same plant populations as for wheat; i.e. set the seeder 25–40% above the setting recommended for wheat as triticale grain is larger than wheat grain and because plants tiller less than wheat. [1]
- Depending on seed size, triticale should be sown at a seeding rate of 75–100 kg/ha.
- Recommended sowing depth for Triticale ranges between 2–5 cm. [2]

Most cultural practices needed for growing triticale can be taken directly from wheat. These include:

- Managing for seedbed preparation
- Seeding rate
- Seeding depth
- Seeding date
- Seeding methods [3]

3.1 Innoculation

Not applicable to this crop.

3.2 Seed treatments

Seed treatments are applied to seed to control diseases such as smuts, bunts or rust, and insects. Triticale is not usually prone to infection from smuts and bunt. However, it is good insurance to apply a seed dressing to the grain when it is being graded. Stripe rust may be a problem in triticale and there are now options to treat seed to provide seedling protection against stripe rust. [4]

Fungicide seed dressings are used to protect the triticale crop from seed borne disease such as loose smut. This treatment should form an integral part of the triticale disease management program and will vary with variety and sowing time. Seek local advice. [5]

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

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

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

1 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

2 DAFWA. (2015). Monitoring sowing depth. https://www.agric.wa.gov.au/mycrop/monitoring-sowing-depth

3 Collier E, Oatway L. (2016). Triticale crop production. Alberta Agriculture and Forestry. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

4 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

5 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

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).

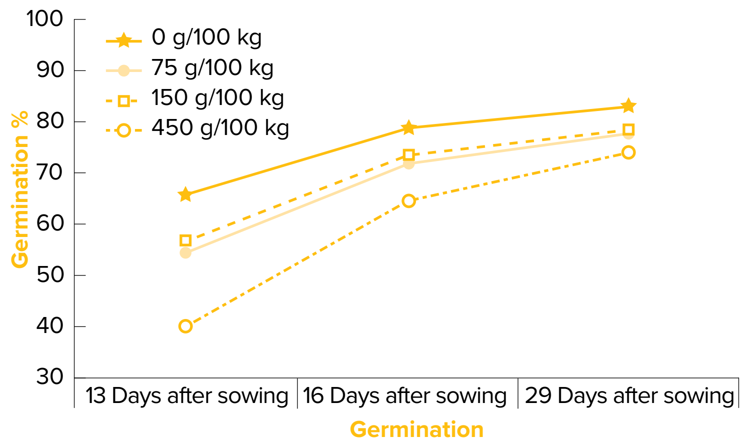

Figure 1: *Impact of seed-treatment fungicide on the rate of germination.*

Source: based on P Cornish 1986

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. [6]

3.2.1 Emergence problems

Caution should be taken in using seed treatment products used in smut and foliar disease control as they may reduce coleoptile length and cause emergence problems under some conditions.

Factors other than seed treatments can cause poor seedling emergence: these include deep sowing, surface crusting, short coleoptile varieties, soil temperatures and trifluralin.

Sowing too deep is a common cause of emergence problems. The coleoptile, which surrounds the first leaf until the shoot emerges, protects and guides the shoot as it grows through the soil. If seed is sown deeper than the length of the coleoptile the plant can fail to emerge.

Because coleoptile lengths vary from one variety to another some varieties can tolerate deeper sowing than others. Coleoptile lengths vary greatly from one batch of seed to another. The source of seed is often more critical than the variety in determining coleoptile length. For this and other reasons farmers should seek to use the best seed possible.

Most emergence problems occur in heavy clay soils where surface sealing occurs. Extra care is required when treated seed and/or trifluralin is used in such soils. [7]

MORE INFORMATION

Cereal seed treatments 2016.

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

7 Wallwork H. SARDI. (2016). Cereal Seed Treatments 2016. http://rustbust.com.au/wp-content/uploads/2013/12/cerealseedtreat2016.pdf

MORE INFORMATION

GRDC Targeted nutrition at sowing Factsheet.

3.2.2 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. [8]

3.3 Time of sowing

Key points:

- Crops sown early within the sowing window will establish faster and have the potential to maximise Water Use Efficiency.
- Early sowing increases the chance of frost damage and can limit weed control.
- WA wheat varieties flower in response to an accumulation of warm temperatures. Many varieties also have a mild cold temperature requirement to delay flowering and some varieties are affected by day length. Research in WA is teasing out the differences.
- Growers need to be selective with varieties for particular sowing times to ensure a spread of flowering dates. Models such as 'Flower Cal' and 'DM' from DAFWA or Yield Prophet™ can assist.
- Late sowing can increase severity of most root diseases early sowing increases severity of a number of leaf diseases. Rusts are not consistently affected by sowing time. [9]

In a Mediterranean environment, such as the WA grain belt, timeliness of sowing is one of the most important aspects of crop agronomy. The optimal planting time for cereals is a compromise. Planting early will increase the chance of frost damage at flowering. With late maturing varieties, it can also increase the bulk of crops and lead to stored soil water being used before flowering. In early maturing varieties, sowing early may actually reduce the bulk of the crop as development is hastened, as well as reduce rooting depth. This can lead to reduced yield potential and reduced access to deeper moisture and nutrients. The optimal sowing date results in flowering after the last frost and with adequate reserves of soil moisture before heat stress begins. [10]

Triticale generally has a similar sowing time requirement to other cereals and should take a priority in the sowing schedule according to its importance to the overall cropping enterprise. Optimum time of sowing depends largely on the variety being grown. Triticale often suffers more from frost damage than wheat, hence it should generally be sown later.

Acting promptly when a sowing window is available has proven critical over many seasons. Delayed sowing has generally proven costly although to sow very early increases frost risk. Triticale appears to be more sensitive to frost damage than other cereals. Dry sowing for a portion of the crop is an option which has proven very successful and can be considered for triticale as well as other cereals. [11]

Long season varieties, such as Endeavour⍀ and Tobruk⍀, can be sown as early as mid-February if seasonal conditions (i.e. rainfall) allows. Tobruk⍀ should only be sown this early if it is going to be grazed. Main season varieties such as the traditional Tahara, and Berkshire⍀ should be sown at the same time as main season wheat, during May and early June.

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

9 GRDC. (2011). Time of sowing – Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/03/time-of-sowing

10 GRDC. (2011). Time of sowing – Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/03/time-of-sowing

11 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

MORE INFORMATION

GRDC Time of Sowing Factsheet – Western Region.

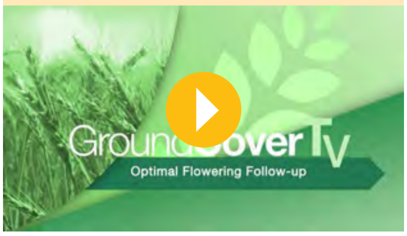
VIDEOS

WATCH: GCTV Extension files: Wheat sowing strategies.

WATCH: GCTV Extension files: Early sowing opportunities.

WATCH: Early sowing in the LRZ.

WATCH: GCTV15: Optimal flowering – follow up.



The widespread adoption of no-till farming means Western Australia's grain growers can now sow crops earlier. Yields are usually higher for earlier sowing within the recommended sowing window. Early sowing speeds establishment but crops can also flower earlier.

Sowing too late lowers yields as grain fill occurs during increasingly hot and dry conditions. Sowing too early will increase the chance of frost damage and can limit weed control options. With late maturity varieties, it can also increase the bulk of crops and lead to stored soil water being used up before flowering (haying off). In fast maturing varieties, sowing very early can reduce the bulk of the crop as development is hastened and root depth reduced. This can lead to lower yield potential and reduce access to deeper moisture and nutrients.

WA research has shown growers can lose yield by sowing too early or too late in years with an autumn break before mid May. However, with a late break (after mid May), early sowing proved best, with yields dropping with progressively later sowing. [12]

Table 1 outlines the optimum flowering window for cereal at locations across the WA wheatbelt. The dates are based on hundreds of sowing date trials across many locations over the past few decades.

Table 1: *The optimum cereal flowering window for locations across the Western Australian grain belt.*

Region	Sowing date
North east	25 August – 15 September
North west	3 September – 23 September
Eastern	1 September – 20 September
Central *	5 September – 25 September
Lakes *	1 September – 20 September
Great southern	16 September – 6 October
South Coastal	3 September – 2 October

* indicates that a damaging frost can occur in the first half of the window in some years

Source: DAFWA.

Lodging

Triticale can lodge because of:

- Height.
- Lush growth under conditions of high moisture and fertility.
- High seeding rates.

Earlier seeding appears to reduce this tendency towards lodging. [13]

3.4 Targeted plant population

The range of sowing rates varies with variety and end use (Table 2). Triticale grain size is larger than wheat, so higher sowing rates are needed to achieve the same plant density. Sowing rates approximately 20% higher than wheat are recommended for triticale (Photo 1). Before determining seed sowing rates, seed germination levels need to be known. [14]

12 GRDC. (2011). Time of Sowing Fact sheet – Western Region. www.grdc.com.au/GRDC-FS-TimeOfSowing

13 Collier E, Oatway L. (2016). Triticale crop production. Alberta Agriculture and Forestry. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

14 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Photo 1: *Triticale paddock sown according to targeted plant population.*

Source: Liebman M in MCCC

For information on seed quality testing, see Section 2: Pre-planting

Aim to achieve the same plant populations as for wheat; i.e. set the seeder 25–40% above the setting recommended for wheat as triticale grain is larger than wheat grain and because plants tiller less than wheat. [15]

Table 2: *Recommended plant populations for different uses of Triticale.* [16]

Purpose/growing conditions	Best sowing rate (kg/ha)
Grain only	60–90
Grain and grazing	100–120
Undersowing pastures	35–45
Irrigation / high rainfall	100–120

Target plant population for Triticale can also vary according to rainfall (Table 3).

Table 3: *Plant establishment densities for triticale.*

Average rainfall (mm)	250–350	350–450	450–550
Planting populations (plants/m^2)	160–180	180–200	200–220

Source: Crop Monitoring Guide – Top Crop Australia (Incitec/GRDC) in GRDC

Triticale does not tiller well. The desired plant density for triticale is 180 plants/m^2 up to 200 plants/m^2 in high rainfall zones. Depending on seed size this equates to a seeding rate of 75–100 kg/ha. If sowing is delayed, or when sowing on light sandy soils, the higher plant density should be the target. [17]

Triticale sown for grazing should be sown at a seeding rate to obtain 150 plants per m^2, which is the same as grazing wheat. Grain only triticale target population can be reduced to 100 to 120 plants per m^2 as for main season grain only wheat.

15 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

16 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

17 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

For each tonne of grain per hectare the rule of thumb target is 40–50 plants/m^2 and about 100 heads/m^2.

APSIM modelling was conducted to explore the optimal sowing density of triticale in Mediterranean-type environments. The tested model was then used to explore management options to maximize triticale yield. The response to sowing density was cultivar and rainfall-environment dependent. The simulation analysis indicated that there was no yield advantage with higher sowing densities with a tall cultivar type in high yielding environments, despite its higher biomass growth rates. The highest yields were achieved at the early sowing date at the sowing densities between 100 and 300 plants/m^2 in the high rainfall regions for both short and the tall cultivars. The simulation study suggests that sowing a short cultivar with a reduced radiation use efficiency but early vigour growth could increase current yields across different regions, seasons and management options in the Mediterranean climate. [18]

When sowing triticale as a cover crop (i.e. undersown with pasture) reduce seeding rate to approximately 10 to 20% of normal, targeting 15—30 plants per m^2. [19]

Plant more weight of triticale seed per unit area than when planting wheat. This is because triticale has larger seeds than wheat (Table 4).

Table 4: *Typical values for characteristics of triticale.*

Seeds/kg	Volumetric grain weight (kg/hL)	Bulk densities	
		Kg/m^3	t/m^3
23,000	65	650	0.65

Source: NSW DPI

Seed size influences plant density, with large seeds requiring a higher sowing rate than smaller seeds to target the same population. '1000 seed weight' is a measure of seed size. It should be determined for each seed lot, as results vary depending on how old the seed is and conditions it has been grown under. [20]

Despite the ability to compensate, targeting a variety's optimum plant density at sowing makes the most efficient use of water and nutrients. To reach a target plant population for the environment and seasonal conditions, adjust sowing rates to allow for:

- sowing date—higher rates with later sowings
- seed germination percentage
- seed size
- seedbed conditions
- tillage, e.g. no-till
- double-cropping
- soil fertility
- soil type
- soil moisture and seasonal outlook
- weed seed burden—higher sow rates for increased plant competition, e.g. if combatting herbicide-resistant ryegrass populations. [21]

18 Bassu, S., Asseng, S., Giunta, F., & Motzo, R. (2013). Optimizing triticale sowing densities across the Mediterranean Basin. *Field Crops Research*, *144*, 167–178.

19 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

20 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

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

3.5 Calculating seed requirements

Key points:

- Plant more weight of triticale seed per unit area than when planting wheat. This is because triticale has larger seeds than does wheat.
- Adjust seeding rates to achieve targeted plant densities for specific triticale uses and conditions.
- Keep in mind that optimum seeding rates vary depending on what the triticale will be used for.
- Choose and manage seeding rates to achieve target plant stand densities in the field.
- Triticale has the largest seed size of all common small-grained cereal crops. Ensure that your seed rate compensates for this.
- Rates are usually adjusted upwards when seeding forage mixtures or inter-cropped triticale.
- For mono-crop triticale forage production, recommended seeding rates are usually 25% higher than seeding rates for grain production.
- In two-component forage-crop blends using triticale, one guideline suggests each component consist of 75 percent of the normal seeding rate for the individual components alone. [22]

It is best to calculate the seeding rate using target plant population, germination percentage and seed count per kilogram, both available on the Seed Analysis Certificate which is available on request when you purchase the seed. [23]

The desired plant density for triticale is 180 plants/m^2 up to 200 plants/m^2 in high rainfall zones. Depending on seed size this equates to a seeding rate of 75–100 kg/ha. If sowing is delayed, or when sowing on light sandy soils, the higher plant density should be the target. [24]

Within limits, higher seeding rates in triticale lead to:

- Higher crop yields.
- Better weed competition.
- Earlier maturity.
- Fewer tillers per plant.
- Shorter plant height.

Seeding rates should generally be adjusted upwards for:

- Large seed size.
- Low seed germination rate.
- Deep seeding (not a recommended practice).
- High moisture and yield potential conditions.
- Heavy textured soils.
- Rough seedbeds.
- Heavy weed pressure conditions (especially in organic production).

Lower seeding rates may be suitable for dry conditions. Triticale does not tiller as freely as wheat, and has greater difficulty in compensating for low stand establishment. Growers should use their experience and local agronomist knowledge to adjust plant density targets to local conditions. [25]

22 Collier E, Oatway L. (2016). Triticale crop production. Alberta Agriculture and Forestry. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

23 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

24 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

25 Collier E, Oatway L. (2016). Triticale crop production. Alberta Agriculture and Forestry. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

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. Note that triticale has a much larger 1000 kernel weight than do other cereals. Average graded seed sizes are:

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

The following formula (Figure 2) can be used to calculate sowing rates, taking into account:

- target plant density
- germination percentage
- 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 [26]

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 2: *Seeding rate calculator.*

3.5.1 Row spacing

Key points:

- In general, increasing row spacing has no effect on cereals when yields are less than 0.5 tonnes per hectare.
- In cereal trials with high yield potential (greater than 3.0 t/ha), significant yield penalties have been recorded with wider row spacing.
- The yields of broadleaf and pulse crops vary in their response to wider row spacing.
- Precision agriculture makes inter-row sowing and fertiliser applications easier at wider row spacing. Weed control can be a major problem.

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

The depth of seed placement and the distance from the adjacent row both influence crop performance. With the greater uptake of no-till and precision farming the opportunities to vary row spacing by crop and sow on the inter-row have increased (Figure 3). However, increasing row spacing is not always beneficial to yield.

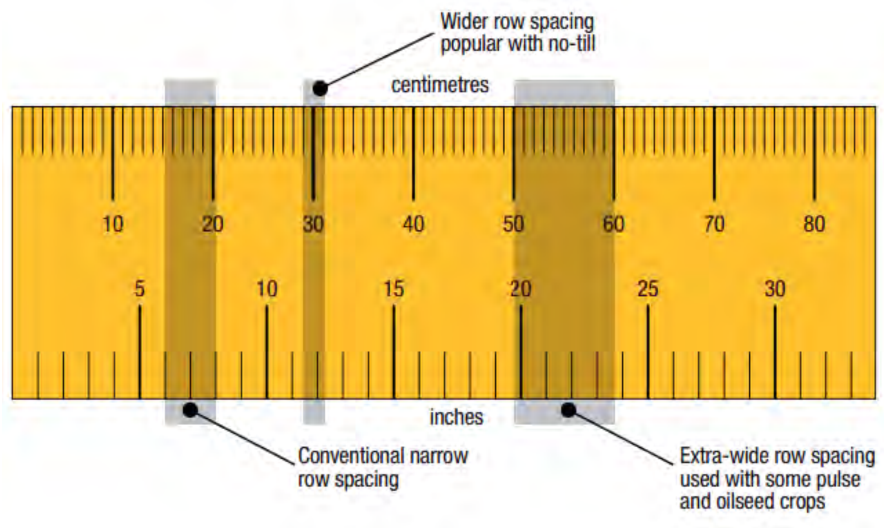


Figure 3: *Common row spacings in metric and imperial measurements.*

Source: GRDC

The traditional row spacing in much of Western Australia has been 18 cm (seven inches) for cereals, but greater adoption of no-till farming systems has increased interest in wider row spacing such as 30 to 50 cm depending on the crop type and region (Figure 4).

The most appropriate row spacing is a compromise between crop yield, ease of stubble handling, optimising travel speed, managing weed competition and soil throw and achieving effective use of pre-emergent herbicides.

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

Western Australia wheat trials on row spacing from nine to 54 cm found wider spacing decreased grain yield. The research found an average eight per cent decrease in yield for each 9 cm increase in row spacing from nine to 54 cm.

Reducing row spacing can increase cereal yields in many areas, but it can create problems with stubble and machinery, such as more blockages at seeding. Cereals grown on wider row spacing tend to be taller and have a greater risk of lodging in high yielding years. At harvest crop lifters may be required.

Figure 4: *Wide row (375 mm) spacing is a hallmark of disc seeding, allowing plants to develop vigorous root systems.*

Source: GRDC

MORE INFORMATION

Crop placement and row spacing – Western region.

Trials at Meckering, WA, examined the impact of row spacing on the yields of wheat and lupins and compared two sowing times – 19 May and 14 June. The trial found there was a greater rate of yield reduction with wide rows in later sown crops, which had less time for canopy development. [27]

3.6 Sowing depth

Optimum planting depth varies with planting moisture, soil type, seasonal conditions, climatic conditions, and the rate at which the seedbed dries. The general rule is to plant as shallow as possible, provided the seed is placed in the moisture zone, but deep enough that the drying front will not reach the seedling roots before leaf emergence, or to separate the seed from any pre-emergent herbicides used. [28]

Recommended sowing depth for Triticale ranges between 2–5 cm. [29]

When using triticale as a forage crop, sowing depth will depend on seasonal conditions and the species and cultivar that is being sown. As a general rule, forage cereals are sown at an average depth of 3–4 cm. However, sowing too deep can affect emergence and shallow sowing can risk desiccation or damage from herbicide uptake. [30]

Triticale seed size is generally bigger than that of commonly grown wheat varieties. Consequently, triticale can be seeded deeper than other small cereals and therefore benefit from stored moisture in the soil, which allows better crop establishment early

27 GRDC (2011). Crop placement and row spacing Factsheet – Western Region. https://grdc.com.au/uploads/documents/grdc_fs_cropplacement_west2.pdf

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

29 DAFWA. (2015). Monitoring sowing depth. https://www.agric.wa.gov.au/mycrop/monitoring-sowing-depth

30 Agriculture Victoria. (2012). Establishing forage cereals.

in the season, particularly in drought-prone areas. Seeding equipment needs to be seed to account for a seed that may be 10 to 20 per cent larger than wheat.

Seed placement during the sowing process is very important when dealing with triticale cultivars. Triticale varieties equal and in many cases exceed the winter hardiness of the best wheats if planted early during autumn and if planted shallow (no more than 2.45 cm deep). At this depth crops should see uniform seedling emergence and early weed competition[31]

Shallow seeding allows for:

- More rapid emergence.
- Early vigour.
- Improved competition with weeds.

Due to its large seed size, triticale is able to emerge from deep seeding. However, this usually results in decreased emergence and less plant vigour. [32]

Seed size influences coleoptile length which is sensitive to sowing depth. Sowing depth influences the rate of emergence and the percentage that emerges. Deeper seed placement slows emergence; this is equivalent to sowing later. Seedlings emerging from greater depth are also weaker, more prone to seedling diseases, and tiller poorly (Photo 2).

Photo 2: *Reduced vigour with increased sowing depth.*

Source: DAFWA

Recent research has confirmed the importance of avoiding smaller-sized seed when deep sowing.

31 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

32 Collier E, Oatway L. (2016). Triticale crop production. Alberta Agriculture and Forestry. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

MORE INFORMATION

Monitoring sowing depth – DAFWA.

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. [33]

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

3.7 Sowing equipment

The use of minimum soil disturbance has advantages for the production of triticale. One study noted a slight yield advantage for triticale grown under zero tillage. Seeding equipment needs to be seed to account for a seed that may be 10 to 20% larger than wheat. [34]

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. [35]

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

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

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

Photo: Rohan Rainbow

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

34 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

35 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

Plant growth and physiology

Key Messages:

- Triticale is quite similar to wheat except it has spreading growth until stem elongation, when the stems extend in the normal erect growth form of wheat. [1]
- Triticale tillers less than wheat.
- Germination optimum temperature is 20°C
- Growth optimum temperature is 10-24°C
- Maximum temperature of survival is 33°C [2]
- Though triticale is generally considered tolerant to salt stress, studies have found that cultivars are slightly less salt tolerant at germination. [3]
- Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals. [4]

Key Characters of triticale (see Table 1):

- Emerging leaves rolled in the shoot.
- Leaf blade flat with a clockwise twist.
- Short membranous ligule.
- Auricles.
- Seed is a grain like wheat. [5]
- Height is about 1–1.5m.
- Leaves are like wheat but larger and thicker. The spikes are also larger. [6]

Table 1: *Main features of triticale.*

Plant part	Description
Cotyledons	1
First leaves	Single, and similar to later leaves
Leaves	Emerging leaves rolled in the shoot
	Blade: parallel sided, flat, clockwise twist when viewed from above, 30–300 mm long, 10–20 mm wide
	Ligule: short membrane
	Auricles: present, occasionally with hairs on the shoulders
	Sheath: rolled, prominent veins, often bluish-green at the base
Stems	Many, unbranched stems arise from base, erect, up to 1,500 mm tall, hollow with solid nodes

1 Hill Laboratories. Crop Guide: Triticale. https://www.hill-laboratories.com/crop-guides/

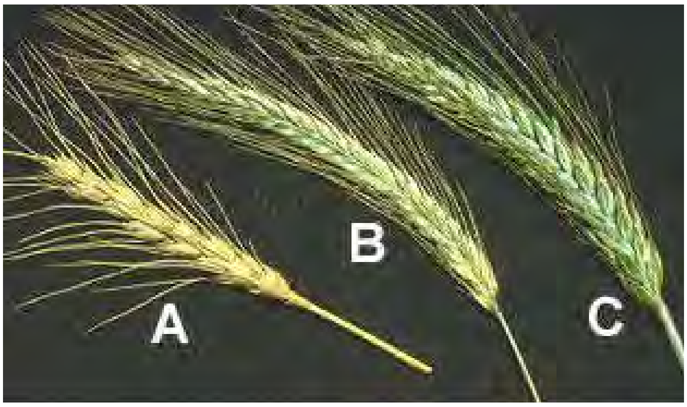
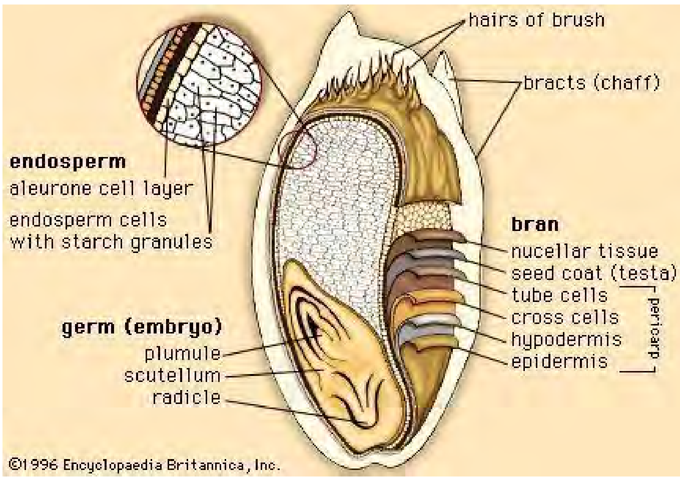
2 Agro Info. Triticale growing. http://agriculture.infoagro.com/crops/triticale-growing/

3 Francois, L. E., Donovan, T. J., Maas, E. V., & Rubenthaler, G. L. (1988). Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. *Agronomy Journal*, *80*(4), 642–647.

4 Jessop, R. S. (1996). Stress tolerance in newer triticales compared to other cereals. In *Triticale: today and tomorrow* (pp. 419–427). Springer Netherlands.

5 Triticale. Collated by HerbiGuide. http://www.herbiguide.com.au/Descriptions/hg_Triticale.htm or www.herbiguide.com.au for more information.

6 Agro Info. Triticale growing. http://agriculture.infoagro.com/crops/triticale-growing/

Plant part	Description
Flower head	Compact spike, squarish in cross-section, awned (Photo 1) [5]
	 **Photo 1:** *vA comparison of flower heads. A: Bread wheat, B: Cereal rye and C: Triticale.* Source: Palomar College
Fruit	Grain
Seeds	Pale brown, dull, elongated oval, wrinkled grain, 8–12 mm long × 2.5–4 mm wide, 23–36 grains per gram; easily rubbed from the husks (Figure 1)
	 **Figure 1:** *Cross-section of cereal grain seed. This is rye, but triticale is similar.* Source: Encyclopaedia Britannica
Roots	Fibrous 2 [7]

Identifying triticale seedlings

Auricles blunt and hairy, leaf-sheath and blade hairy. Ligule of medium length. Leaf-blades twist clockwise.

Triticale and wheat are difficult to distinguish since their vegetative characters are similar. Removal of the seedling from the soil and observation of the grain shell may be a means of distinguishing wheat from triticale.

7 Triticale. Collated by HerbiGuide. http://www.herbiguide.com.au/Descriptions/hg_Triticale.htm or www.herbiguide.com.au for more information.

Wheat grain shells tend to be lighter in colour than triticale. Wheat shells are oval; triticale grain shells are oblong. [8]

4.1 Germination and emergence

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

- water absorption (imbibition)
- activation
- visible germination

Phase 1. Water absorption (GS01)*

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

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

Seeds begin to germinate at a relative humidity of 97.7%. Soil so dry that roots cannot extract water still has a relative humidity of 99%, much higher than that of a dry seed. So even in dry conditions, there can be enough moisture for the seed to absorb and begin Phase 1, but it takes longer than in moist conditions.

Phase 2. Activation (GS03)

Once the embryo has swollen, it produces hormones that stimulate enzyme activity. The enzymes break down starch and protein stored in the seed to sugars and amino acids, providing energy to the growing embryo. The larger the seed, the more starch and therefore energy it will have. If the seed dries out before the embryo starts to grow, it remains viable. Phase 2 continues until the rupture of the seed coat, the first visible sign of germination.

Phase 3. Visible germination (GS05–GS09)

In Phase 3, the embryo starts to grow visibly. The radicle emerges, followed soon after by other primary roots and the coleoptile. The enzymes produced in Phase 2 mobilise sugars and amino acids stored in the seed and enable their transfer to the growing embryo. [9]

Triticale cultivation can be carried out in subtropical, moderately mild and moderately cold climates. Optimal temperatures are:

- Germination optimum temperature is 20°C
- Growth optimum temperature is 10-24°C
- Minimum temperature of survival is -10°C
- Maximum temperature of survival is 33°C [10]

In a study comparing the tolerance of cereal seeds to a range of temperatures, Triticale was more sensitive than wheat and barley to germination temperature. [11]

Thermal time to first seedling emergence for triticale has been recorded at between 113–119 days, and 127–130 days for 95% emergence. This equates to a rate of seedling emergence of 3.3–3.1% seedlings °Cd-1 (thermal time).

Very low temperatures can damage triticale seedling during germination and emergence (Photo 2).

8 Agriculture Victoria. (2012). Identification of cereal seedlings. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/identification-of-cereal-seedlings

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

10 Agro Info. Triticale growing. http://agriculture.infoagro.com/crops/triticale-growing/

11 Buraas, T., & Skinnes, H. (1985). Development of seed dormancy in barley, wheat and triticale under controlled conditions. *Acta Agriculturae Scandinavica*, *35*(3), 233–244.

Photo 2: *Cold temperature damage in triticale.*

Source: Alberta Ag

Though triticale is generally considered tolerant to salt stress, studies have found that cultivars are slightly less salt tolerant at germination than they were after the three-leaf stage of growth. [12]

Early research found that saline soils could impair triticale emergence, with the application of Calcium sulphate (CaS04) helping to increase emergence under saline conditions. [13]

One study found that decreases in osmotic potential caused a reduction in germination percentage and seedling growth. Drought conditions had more negative effects on germination and seedling growth than that of Sodium Chloride. Germination and seedling growth were higher in large seeds than in small seeds in control solution and under osmotic stress. In addition, it was observed that seedlings obtained from larger seeds survived even at the low osmotic potential, whereas seedlings obtained from small seeds did not survive under intensive stress conditions. [14]

Excessive herbicide treatments may also limit germination in triticale. The successive effect of five herbicide variants (isoxaben, chlorsulfuron, isoproturon, chlortoluron and control) on the germination and plant growth of triticale cultivars has been explored. Germinative energy and germinating power of winter triticale seeds, obtained from plants treated with herbicide, were generally lower, in particular for the isoproturon and chlorsulfuron variants. [15]

Aeration of seed during storage can help to ensure high seed viability and germination rates. [16]

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

The coleoptile (Photo 3) is well developed in the embryo, forming a thimble-shaped structure covering the seedling tube leaf and the shoot. Once the coleoptile emerges from the seed, it increases in length until it breaks through the soil surface. The fully elongated coleoptile is a tubular structure about 50 mm long and 2 mm in diameter. It is white, except for two strands of tissue that contain chlorophyll. The end of the coleoptile is bullet-shaped and is closed except for a small pore, 0.25 mm long, and a short distance behind the tip.

12 Francois, L. E., Donovan, T. J., Maas, E. V., & Rubenthaler, G. L. (1988). Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. *Agronomy Journal*, *80*(4), 642–647.

13 Norlyn, J. D., & Epstein, E. (1984). Variability in salt tolerance of four triticale lines at germination and emergence. *Crop science*, *24*(6), 1090–1092.

14 Kaydan, D., & Yagmur, M. (2008). Germination, seedling growth and relative water content of shoot in different seed sizes of triticale under osmotic stress of water and NaCl. *African Journal of Biotechnology*, *7*(16), 2862.

15 Sławomir, S., & Robert, M. (1996). Successive effect of herbicides on triticale seed germination and plant growth. In *Triticale: Today and Tomorrow* (pp. 743–747). Springer Netherlands.

16 Baxter N. (2014). Ground Cover Issue113: Nov-Dec 2014 – Study finds aeration improves seed germination. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-113-NovDec-2014/Study-finds-aeration-improves-seed-germination

Photo 3: *Cereal seed germination showing the coleoptile (green) emerging to reach soil surface.*

Source: ICARDA

When the coleoptile senses light it stops growing and the first true leaf pushes through the pore at the tip. Up to this point, the plant is living on reserves within the seed. [17] The difference between the coleoptile and the first true leaf is that the coleoptile knows which way the soil surface is. If it does not reach the surface, the first leaf may emerge under the soil and grow in any direction.

Optimum planting depth varies with planting moisture, soil type, seasonal conditions, climatic conditions, and the rate at which the seedbed dries. The general rule is to plant as shallow as possible, provided the seed is placed in the moisture zone, but deep enough that the drying front will not reach the seedling roots before leaf emergence, or to separate the seed from any pre-emergent herbicides used. [18]

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 (Photo 4). Make sure seed-to-soil contact occurs. [19]

Photo 4: *Triticale seedling emergence.*

Source: Kaspar T in MCCC

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

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

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

Seed size influences coleoptile length which is sensitive to sowing depth. Sowing depth influences the rate of emergence and the percentage that emerges. Deeper seed placement slows emergence; this is equivalent to sowing later. Seedlings emerging from greater depth are also weaker, more prone to seedling diseases, and tiller poorly.

Recent research has confirmed the importance of avoiding smaller-sized seed when deep sowing.

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. [20]

Photo 5: *GS11 – 1st unfolded leaf. Deep sown seedling (left) and correctly sown seedling (right).*

Source: GRDC

4.1.1 Soil moisture

Soil moisture influences the speed of germination. Germination is rapid if the soil is moist. When the soil dries to near the permanent wilting point, the speed of germination slows. Instead of 5 days at 7°C when there is adequate moisture, germination will take 10 days at 7°C when soil reaches permanent wilting point.

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

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

This ability to start and stop the germination process (in response to conditions) before the roots and coleoptile have emerged is an important consideration when dry sowing.

If the seedbed dries out before the coleoptile has emerged, the crop needs to be monitored to determine whether it will emerge, so the critical decision to re-sow can be made.

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

Stubble reduces the impact of raindrops on the soil surface and helps to prevent formation of soil crusts. Stubble retention also encourages biological activity and increases the amount of organic matter, which improves the stability of the soil by binding the soil particles together. [21]

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

4.2.1 Temperature

One study explored the effect of high temperatures at different growth stages on triticale. Thermal treatments consistently reduced grain yield ($p<0.05$), the magnitude of the effect ranged between 5 and 52%. The highest effect was found when temperature increased during stem elongation (yield decrease: 46%), lowest when treatments were imposed during heading-anthesis (15%) and intermediate for treatments imposed during booting-anthesis (27%). Greatest yield losses were seen when plants were exposed to high temperatures in the booting-anthesis stage. [22]

Temperature can also affect the photosynthesis and respiration rates of triticale, leading to changes in growth. [23]

High temperatures are known to induce rapid growth which diminishes the cell pool of metabolites (e.g. amino acids, nitrates, carbohydrates) and therefore nutritional quality. [24]

4.2.2 Photoperiod

There is limited research into the effects of photoperiod on triticale growth, and results vary between studies.

The developmental responses to temperature and photoperiod of five triticale cultivars and one wheat cultivar were examined in the field in southern Australia in 1974. Six times of sowing and the use of supplemental illumination, providing an 18 hour daylength at one of the two sites, created a range of different photoperiod and temperature treatments. The order in which the varieties reached the various developmental stages changed very little with the successive times of sowing, but differed when the natural daylength was compared with the 18 hour regime. The duration of each phase was shortened by a longer mean daily photoperiod or a higher mean daily temperature, the photoperiod having a greater effect than the temperature. [25]

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

22 Ugarte, C., Calderini, D. F., & Slafer, G. A. (2007). Grain weight and grain number responsiveness to pre-anthesis temperature in wheat, barley and triticale. *Field Crops Research*, *100*(2), 240–248.

23 Winzeler, M., McCullough, D. E., & Hunt, L. A. (1989). Leaf gas exchange and plant growth of winter rye, triticale, and wheat under contrasting temperature regimes. *Crop science*, *29*(5), 1256–1260.

24 McGoverin, C. M., Snyders, F., Muller, N., Botes, W., Fox, G., & Manley, M. (2011). A review of triticale uses and the effect of growth environment on grain quality. *Journal of the Science of Food and Agriculture*, *91*(7), 1155–1165.

25 Brouwer, J. B. (1977). Developmental responses of different hexaploid triticales to temperature and photoperiod. *Animal Production Science*, *17*(88), 826–831.

Spring Triticale is insensitive to photoperiod and have limited tillering. During the early stages of triticale breeding, spring types used in northern latitudes tended to be daylight sensitive, requiring in excess of 12 hours of light to initiate the change from the vegetative state. The development of daylight insensitive types has greatly eliminated this problem for the production of triticale at lower latitudes where day lengths are short. [26]

IN FOCUS

Yield determination in triticale as affected by radiation in different development phases

A field experiment was carried out with two triticales, differing in tillering capacity, subjected to shading treatments at five different timings from early tillering to maturity. Results showed that reductions in grain yield were more significant when shading was imposed during 3 weeks before and 1 week after anthesis. Reductions in grain yield by shading treatments were associated with lower number of grains per m^2 more than with changes in the average grain weight. Reductions in grains per m^2 were due to reductions in the number of fertile florets per spike, affecting grains per spike. The assimilate acquisition by the spikes during the critical period was a key determinant of floret survival. Grain number per m^2 was related with photothermal quotient during 30 days before anthesis and spike dry weight at anthesis, though the goodness of the prediction compared with wheat, was lowered by poorer grain setting percentage. [27]

4.2.3 Salinity

Research in Europe suggests that triticale is a fairly salt tolerant crop, and recommends its cultivation in saline soils instead of crops that are salt sensitive. [28]

Research in the US found that relative grain yield for triticale cultivars were unaffected by soil salinity up to 7.3 dS/m (electrical conductivity of the saturated-soil extracts in the rootzone). Each unit increase in salinity above 7.3 dS/m reduced grain yield by 2.8%. These results place triticale in the salt-tolerant category. Yield reduction resulted primarily from a reduction in spike number rather than from lower weight per spike or lower weight per individual seed. Cultivars were slightly less salt tolerant at germination than they were after the three-leaf stage of growth. [29]

26 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

27 Estrada-Campuzano, G., Miralles, D. J., & Slafer, G. A. (2008). Yield determination in triticale as affected by radiation in different development phases. *European Journal of Agronomy*, *28*(4), 597–605.

28 Koebner, R. M., & Martin, P. K. (1996). High levels of salt tolerance revealed in triticale. In *Triticale: Today and Tomorrow* (pp. 429–436). Springer Netherlands.

29 Francois, L. E., Donovan, T. J., Maas, E. V., & Rubenthaler, G. L. (1988). Effect of salinity on grain yield and quality, vegetative growth, and germination of triticale. *Agronomy Journal*, *80*(4), 642–647.

IN FOCUS

The Effect of Salt Stress on Photosynthetic Characteristics and Growth of Various Triticale

Six varieties of triticale cultivars were treated with NaCl in 0,50,100,200,300 mmol/L concentrations. After 15 days the photosynthetic rate, transpiration rate, stomatal conductance, intercellular CO_2 concentration, root length, height of seedling and fresh weight were examined. Findings indicate that the 50 mmol/L NaCl process can promote the photosynthetic rate and the growth of the seedlings. With the increase of the concentration of NaCl, the net photosynthetic rate, transpiration rate and stomatal conductance of the seedlings decreased, the intercellular CO_2 concentration showed regular changes, with the growth of seedlings impeded. [30]

One study found that germination of triticale under saline soil conditions could be improved by applying Salicylic acid. [31]

4.2.4 Drought

Since the early development of triticale, its tolerance to drought stress has increased compared to other cereals. [32]

A wide range of genotypic variability exists within triticale strains/cultivars with respect to drought tolerance. In addition, the usefulness of other parameters, e.g. leaf gaseous exchange and chlorophyll content, for measuring drought tolerance was assessed. Chlorophyll fluorescence and relative loss of intracellular electrolytes from leaf tissues were good indicators of drought resistance. An indication of drought tolerance in triticale has also been given by osmo-regulation capacity, light harvesting capacity and blue fluorescence. [33]

IN FOCUS

The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment

Stomatal conductance has proven to be important in determining the amount and efficiency with which water is used by cereal crops and the productivity of those crops. Field experiments in Italy compared stomatal conductance and stomatal conductance-related traits (i.e., carbon-isotope discrimination and infrared canopy temperature) of durum wheat and triticale in different environments, to evaluate the impacts on leaf transpiration efficiency and on water- and radiation-use efficiency. A large variation in stomatal conductance was observed between species, although differences decreased as development proceeded. The

30 The effect of salt stress on Photosynthetic characteristics and growth of various triticale. http://en.cnki.com.cn/Article_en/CJFDTOTAL-HSSZ200904022.htm

31 Ghodrat, V., Rousta, M. J., & Zare, N. (2013). Improving germination and growth of Triticale (X Triticosecale Wittmack) by priming with Salicylic acid (SA) under saline conditions. *International Journal of Agriculture and Crop Sciences*, *5*(16), 1832.

32 Jessop, R. S. (1996). Stress tolerance in newer triticales compared to other cereals. In *Triticale: today and tomorrow* (pp. 419–427). Springer Netherlands.

33 McGoverin, C. M., Snyders, F., Muller, N., Botes, W., Fox, G., & Manley, M. (2011). A review of triticale uses and the effect of growth environment on grain quality. *Journal of the Science of Food and Agriculture*, *91*(7), 1155–1165.

greater stomatal conductance of triticale before anthesis did not imply a greater soil water depletion because the good water availability allowed the development of dense canopies exerting a relevant aerodynamic resistance on water vapor fluxes. The greater radiation-use-efficiency of triticale associated with its greater stomatal conductance in pre-anthesis resulted in a greater biomass than durum wheat in correspondence with similar amounts of radiation intercepted and of water used. Transpiration efficiency of triticale was also higher at the crop level, despite similar transpiration efficiency at the leaf level. The greater stomatal conductance of triticale confers an advantage to this species in terms of both water and radiation use-efficiency despite the typical terminal drought affecting winter cereal crops in Mediterranean environments. [34]

In one experiment, triticale cultivars were subjected to drought during the tillering phase and heading phase, and maintained osmotic regulation (high osmotic potential). Consequently, these cultivars were able to maintain better leaf hydration and photosynthetic functioning. It is suggested that these are adaptation mechanisms, acting during drought, which can involve the inhibition of the utilization of carbohydrates in the growth processes of leaves and to maintain high osmotic potential of the cell sap. [35]

Water stress

IN FOCUS

Triticale grain yield and physiological response to water stress

Water availability in semi-arid regions is increasingly becoming threatened by erratic rains and frequent droughts leading to over-reliance on irrigation to meet food demand. Improving crop Water Use Efficiency (WUE) has become a priority. A two-year study was carried out with four moisture levels, ranging from well-watered (430–450 mm) to severe stress (SS) (220–250 mm), combined with four commercial triticale genotypes grown under field conditions in a hot, arid, steppe climate in South Africa. The results showed that moisture level significantly influenced grain yield and intrinsic WUE in triticale. Well-watered conditions increased grain yield, which ranged from 3.5 to 0.8 t ha−1and4.9–1.8 t ha−1in 2013 and 2014 respectively. Intrinsic WUE increased with decreasing moisture level. Flag leaf photosynthesis and pre-anthesis assimilates contribute much less carbon to grain filling under water stress than previously thought. [36]

34 Motzo, R., Pruneddu, G., & Giunta, F. (2013). The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment. *European Journal of Agronomy*, *44*, 87–97.

35 Hura, T., Hura, K., & Grzesiak, M. (2011). Soil drought applied during the vegetative growth of triticale modifies the physiological and biochemical adaptation to drought during the generative development. *Journal of Agronomy and Crop Science*, *197*(2), 113–123.

36 Munjonji, L., Ayisi, K. K., Vandewalle, B., Haesaert, G., & Boeckx, P. (2016). Combining carbon-13 and oxygen-18 to unravel triticale grain yield and physiological response to water stress. *Field Crops Research*, *195*, 36–49.

4.3 Plant growth stages

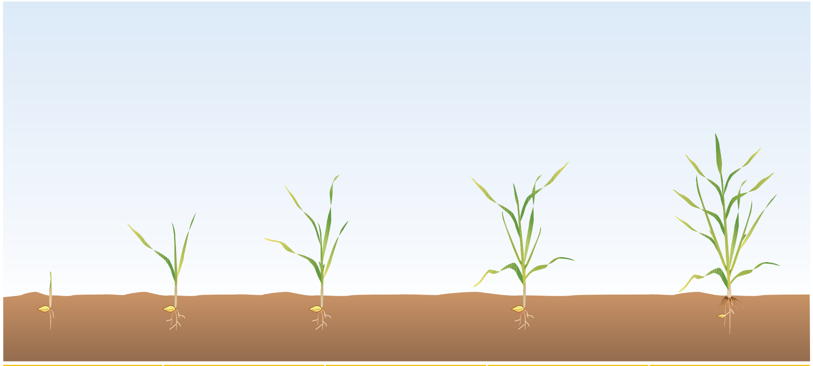
Plant development is divided into several stages: germination and early seedling growth, tillering and vegetative growth, elongation and heading, flowering, and kernel development. Numerical scales have been developed for quantifying growth stages of small grains. A growth stage key provides farmers, advisers and researchers with a common reference for describing the crop's development. Management by growth stage is critical to optimise returns from inputs such as N, herbicides, plant growth regulators and fungicides.

4.3.1 Zadoks cereal growth stage key

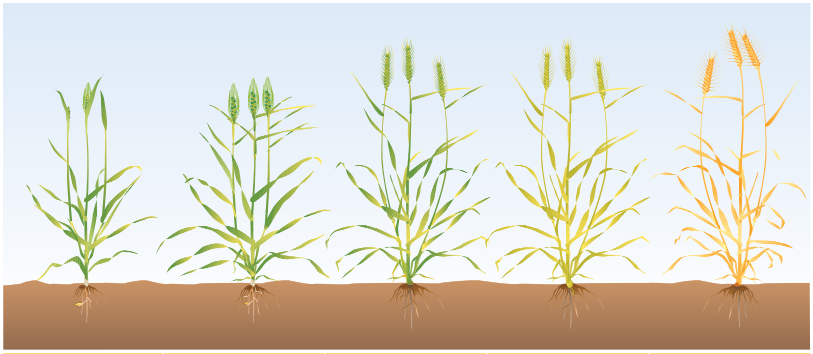
Zadoks growth stages in relation to 10 distinct development phases are depicted in Figure 2 and examples of cereal plants at various growth stages in Figure 3 and described in Table 2.

The Zadoks system uses a 2-digit code to refer to the principal stages of growth from germination (stage 0) through kernel ripening (stage 9). The second digit subdivides each principal growth stage. For instance, '13' indicates that in principal stage 1 (seedling growth) subdivision 3, leaves are at least 50 percent emerged from the main stem; '75' indicates that in principal stage 7 (kernel development) subdivision 5, the grain is at the medium milk stage.

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



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



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

Figure 2: *Zadoks cereal growth stages.*

Source: GRDC

Table 2: *Cereal Growth Stages.*

Crop growth stage					
2-leaf stage	Start of tillering	Tillering stage	Fully tillered stage	Start of jointing	Early boot stage
Two leaves (L) have unfolded; third leaf present, yet to fully expand.	First tiller (T1) appears from between a lower leaf and the main shoot. Usually 3 or 4 leaves are on the main tiller.	Tillers come from the base where leaves join the stem and continue forming, usually until there are 5 leaves on the main shoot. Secondary roots developing.	Usually no more tillers form after the very young head starts forming in the main tiller. Tillering completed when first node detected at base of main stem.	Jointing or node formation starts at the end of tillering. Small swellings – joints – form at the bottom of the main tiller. Heads continue eveloping and can be seen by dissecting a stem.	The last leaf to form – the flag leaf – appears on top of the extended stem. The developing head can be felt as a swelling in the stem
Zadoks decimal code					
2 leaves unfolded (Z12).	4 leaves unfolded (Z14). Main shoot and 1 tiller (Z21).	5 leaves on main shoot or stem (Z15). Main shoot and 1 tiller (Z21).	6 leaves on the main shoot or stem (Z16). Main shoot and three tillers (Z23).	First node formed at base of main tiller (Z31).	Z35–Z45.

Source: NSW DPI

Table 3: *Zadoks growth key – key points:*

- The Zadoks Growth Stage key does not run chronologically from GS00 to 99, for example when the crop reaches 3 fully unfolded leaves (GS13) it begins to tiller (GS20), before it has completed 4, 5, 6 fully unfolded leaves (GS14, 15, 16).
- 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 e.g. GS22 is main stem plus 2 tillers up to GS29 main stem plus 9 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 (2nd node on the main stem) with 3 tillers and 7 leaves on the main stem would be at GS32, 23, 17, yet practically would be regarded as GS32, since this describes the most advanced stage of development.
- NOTE: after stem elongation (GS30) the growth stage describes the stage of the main stem, it is not an average of all the tillers. This is particularly important with fungicide timing e.g. GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged. [37]

4.3.2 Germination and early seedling growth

The kernel (seed), or caryopsis, consists of a seed coat surrounding an embryo and endosperm. The embryo contains the seedling root (radicle), stem, and growing points of the new grain plant. The endosperm provides nutrients for growth until the first true leaves emerge and the root system is established. When moisture conditions are favorable, the seed germinates with the emergence of the radicle and the coleoptile, the first leaf that forms a protective sheath around the first four leaves.

The primary root system includes the radicle and roots that develop from stem tissue near the kernel (Figure 3). It may penetrate the soil up to 30 cm and provides the developing seedling with water and nutrients. The primary root system supports plant growth until tillering, when the secondary root system becomes the main root system of the plant. The primary roots may persist for the life of the plant and can

37 GRDC (2005). Cereal growth stages – the link to crop management. https://www.researchgate.net/file.PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798

support some plant growth through the heading stage. The first secondary roots appear at the tillering node about 2.5 cm below the soil line at the two- or three-leaf stage. These roots are always produced at about the same distance below the soil's surface, regardless of the depth at which the seed is planted. The secondary root system makes up the major part of the fully developed plant's root system.

Root development approaches the maximum at about the boot stage. The 'boot' represents the swollen flag leaf sheath within which the developing spike is located after being pushed up as the stem has elongated.

As the seedling root system is forming, the coleoptile grows upward and ruptures, allowing the first leaf to begin unfolding as soon as the coleoptile tip breaks the soil surface. Emergence usually occurs 6 to 20 days after sowing, depending on temperature and moisture. Emergence can be later than 20 days after sowing under prolonged cold or dry conditions. Initial formation of leaves and stems occurs at the shoot apex, which is located just below the soil surface.

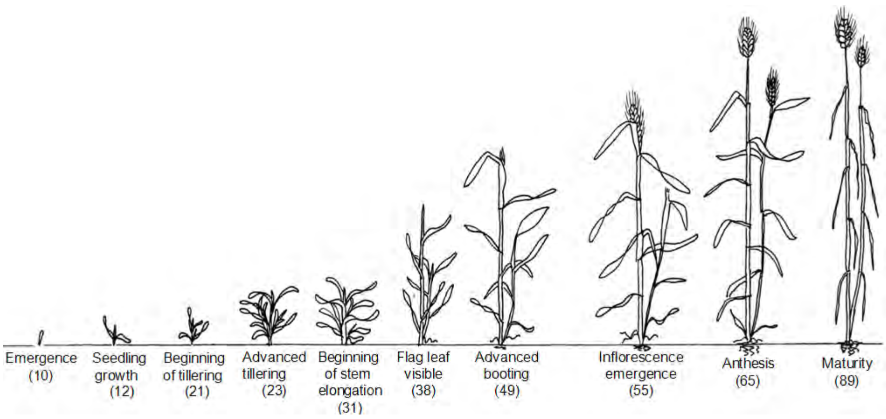


Figure 3: *Growth stages of small-grain cereals. Numbers correspond to the Zadoks growth key.* [38]

4.3.3 Tillering and vegetative growth

Branching in small grains is called tillering or stooling. Individual branches are called tillers, and the mass of tillers is the stool. Two to four primary tillers develop from buds in the crown area of the main stem. Secondary tillers develop from buds in the axils of leaves at the base of the primary tillers. Tertiary tillers may develop from buds in the axils of leaves at the base of the secondary tillers.

The number of tillers that form is influenced by plant density (more with low plant density), soil moisture and nutrient supply (more with high supply), sowing date (more with early sowing), temperature (more under cooler temperatures), and cultivar. Water stress, nutrient deficiency, low temperatures, weed competition, and pest damage during early development reduce the number of tillers.

The emergence of primary tillers is synchronous with the emergence of leaves on the main stem of the plant (Photo 6). The first primary tiller begins developing as leaf 4 of the main stem emerges; the second primary tiller begins developing as leaf 5 emerges. Subsequent primary tillers begin developing when subsequent leaves emerge.

Successive tillers develop fewer leaves; flowering and grain development is only slightly delayed on later-developing tillers. Before the main stem and tillers begin to elongate, the spikes differentiate. The precursors (primordia) of all florets (flowers with lemma and palea, the outer bracts) or spikelets (units consisting of several florets on a thin axis, subtended at the base by two bracts, or glumes) develop at this time.

38 Royo, C., & Villegas, D. (2011). *Field measurements of canopy spectra for biomass assessment of small-grain cereals*. INTECH Open Access Publisher.

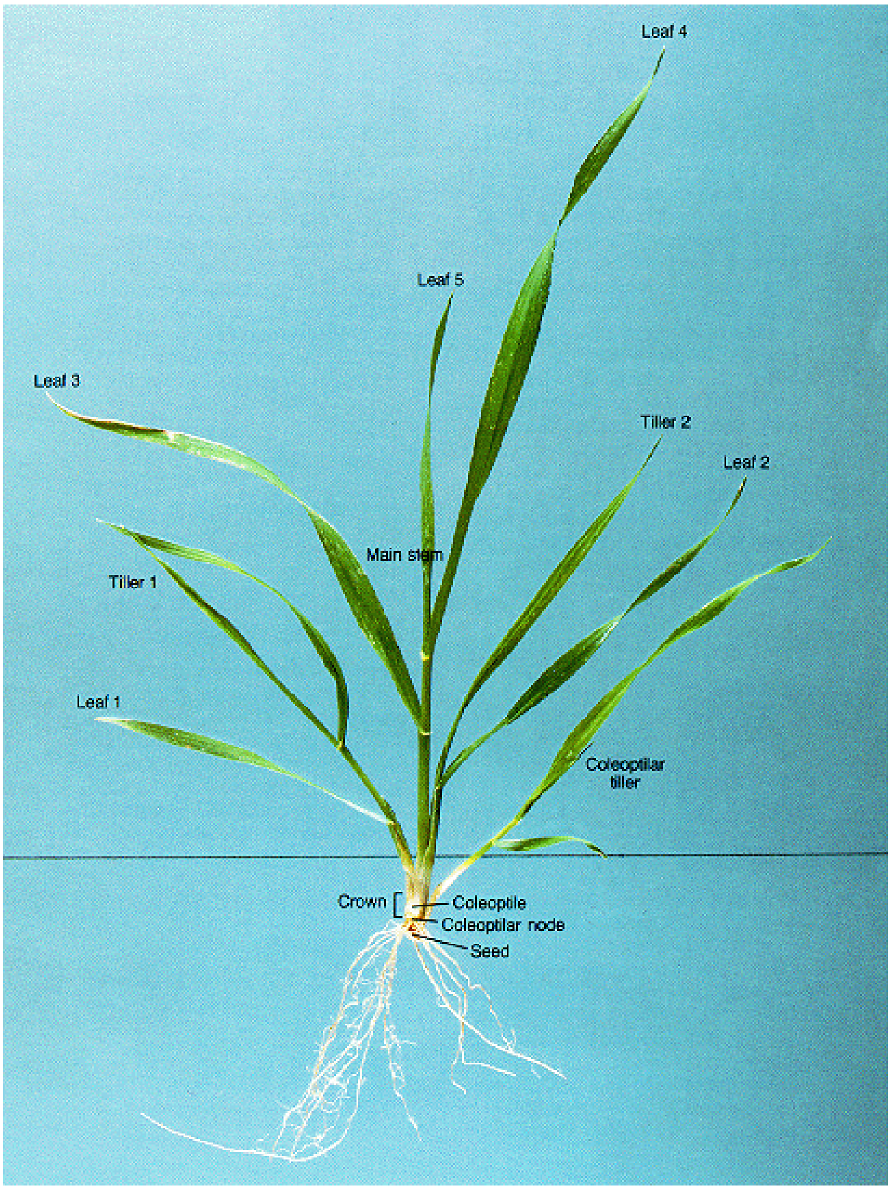


Photo 6: *Plant parts in relation to growth stage.*

Source: Wisc Edu

4.3.4 Stem elongation and heading

Stem elongation, or jointing, occurs when stem internodes increase in length and bring the nodes above ground. The uppermost five or six internodes elongate, beginning with the lowest of these. The appearance of the first node above ground marks the beginning of jointing. Jointing begins about the time all spikelet primordia have formed. The flowering structure (inflorescence) of triticale, wheat and barley is called a spike. Inflorescences are composed of spikelets, each consisting of one or more flowers, called florets, at nodes along the spike or panicle.

During stem elongation, the spike increases in length from about 3 mm to its final size, and individual florets mature. All stages of spikelet development in triticale, wheat and barley begin near the middle of the spike and proceed toward the base and tip.

The last leaf of the small grain plant to emerge is called the flag leaf. When the flag leaf blade has completely emerged, the appearance of its ligule (a short membrane on the inside of the leaf at the junction of the blade and sheath) marks the beginning of the boot stage. During boot stage the enlarging spike swells and splits the sheath of the flag leaf. Heading begins when the spike begins emerging through the flag leaf collar and is complete when the base of the spike is visible.

4.3.5 Flowering and grain filling

The flowers of triticale, wheat, barley, and oat are self-pollinated; most of the pollen is shed before the anthers emerge from the florets. Flowering (anthesis, or pollen shed) usually occurs within 2 to 4 days after spikes have completely emerged from the boot. If emergence occurs during hot weather, flowering may occur while spikes are still in the boot. Most cells of the grain endosperm are formed during a period of rapid cell division following pollination. These cells enlarge and accumulate starch during grain filling. Most of the carbohydrate used for grain filling comes from the photosynthetic output of the flag leaf. Developing spikelets compete for limited supplies of photosynthate and nitrogen. The smallest, slowest-growing florets, which occur at the tip of the spikelet, are often unable to obtain enough nutrients to keep growing. Some spikelets at the base of the cereal spike also may fail to develop.

The stages of grain ripening are called milk, soft dough, hard dough, hard kernel, and harvest ripe (Photo 7). Dry matter begins accumulating in the kernel during the milk stage. During early milk stage, a clear fluid can be squeezed from the kernel. During late milk stage, milky fluid can be squeezed from the kernel. Most of the dry matter accumulates during the soft dough stage. Loss of water gives the kernel a doughy or mealy consistency. At the end of the hard dough stage the kernel reaches physiological maturity, water content drops to about 30 percent, and the plant loses most of its green color. The kernel contents can be divided with a thumbnail. At the hard kernel stage the plant is completely yellow and water content of the kernel is 20 to 25%. The contents of the kernel are difficult to divide with a thumbnail, but its surface can be dented. When kernel moisture content has dropped to 13 to 14%, the grain is harvest ripe. The surface of the kernel cannot be dented with a thumbnail. [39]

39 Jackson L, Williams J. (2006). Small grain production 2 – Growth and developments of Small grains. University of California. http://anrcatalog.ucanr.edu/pdf/8165.pdf

Photo 7: *Stages of cereal grain ripening from the milky stage (top) to the harvest ripe stage(bottom),*

Source: UCANR

4.3.6 Triticale growth

One of the advantages of triticale compared to wheat and barley is its early vigour, which enables fast crop growth during the first stages of development and a rapid cover of the soil by the crop canopy (Photo 8).

Photo 8: *Triticale 50 days after emergence.*

Source: Kaspar T in MCCC

Trials in the UK compared triticale growth to wheat growth. It found a noticeable difference between the species in the length of key growth phases. The growth phase from drilling to growth stage, (GS31 - first node detectable) was, on average, 8.5 days shorter for the triticale, and GS31 to flowering (GS61) 1.75 days shorter than the wheat. The grain filling phase (GS61 to harvest) was considerably (10.6 days) longer in the triticale, though (Figure 4). However, this longer grain filling phase did not confer a greater thousand grain weight (TGW) to the triticale varieties. Instead, this extra time was needed to fill the greater number of grains per ear that triticale has compared to wheat.

Despite having a shorter duration to flowering, triticale formed more biomass during this phase than wheat. Both triticale varieties formed more biomass than both wheats, but only for Benetto were the increases significant. This was associated with both a greater number of stems and a greater biomass per stem. The relative differences between the biomass of the different species at GS61 translated into differences at harvest, where triticale produced greater yield. It can be seen that the yield advantages of triticale come from a combination of a greater number of ears per m^2 and more grains per ear that are filled during a longer grain-filling period. These are supported by greater biomass that is evident throughout the season. [40]

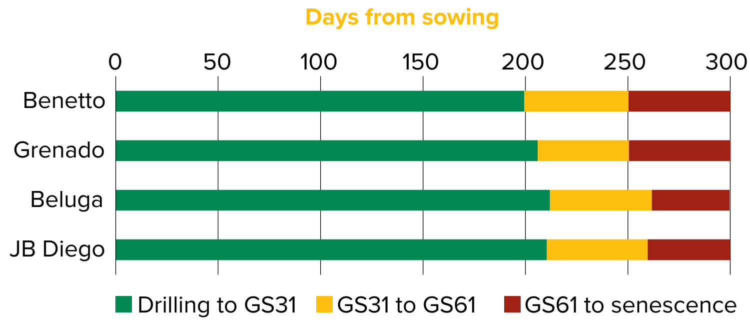


Figure 4: *Length of key growth phases of two triticale (Benetto, Grenado) and two wheat (Beluga, JB Diego) varieties: Drilling to GS31, GS31 to GS61, and GS61 to harvest. Results are an average of two experiments. Plots grown at 180 kg N/ha.* [41]

Although triticale has a very large seed and a very robust embryo, in cooler climates it has been observed in the early stages of development to be slow growing compared to other cereal species. This may be due to the early development of a massive

40 Clarke S, Roques S, Weightman R, Kindred D. (2016). Understanding Triticale. https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf

41 Clarke S, Roques S, Weightman R, Kindred D. (2016). Understanding Triticale. https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf

root system versus early top growth, which is in contrast to the general perception that triticale as a species is a very robust and competitive crop during its growth in many of its adapted growing zones. Triticale seed size is generally bigger than that of commonly grown wheat varieties. Consequently spring triticale can be seeded deeper than other small cereals and therefore benefit from stored moisture in the soil, which allows better crop establishment early in the season, particularly in drought-prone areas. Seeding equipment needs to be seed to account for a seed that may be 10 to 20% larger than wheat. [42]

Spring triticale does not require vernalisation to go from vegetative to reproductive stages. These types exhibit upright growth and produce much more forage early in their growth. They are insensitive to photoperiod and have limited tillering. [43]

Triticale cultivars tiller less profusely than wheat cultivars of similar maturity. [44] Significant differences in tillering abilities between triticale and wheat influences management practices, such as seed rate or amount of fertiliser applied. Adding N increased tiller and ear numbers in three cereals (triticale, wheat and rye), however, triticale produced fewer tillers and the response to N was significantly greater than wheat and rye. Triticale compensated for having fewer tillers by producing more spikelets per ear and setting more grains/spikelet, thereby producing more grains/pot than the other two cereals. Average kernel weights of triticale were also greater than those of wheat and rye. Total water use (WUE) of triticale was less than that of the other cereals, particularly at the higher rates of N. This experiment showed that the yield of triticale was not restricted by less profuse tillering and it was able to compensate by producing more grains per ear and heavier kernels. Indeed, Currency's restricted tiller production was associated with lower WU and higher WUE. [45]

Triticale flowers earlier than most wheats, but matures at about the same time.

IN FOCUS

Variation in temperate cereals in rainfed environments II. Phasic development and growth

Barley yields more grain and total biomass than does triticale which in turn yields more biomass than do bread wheat, durum wheat and oats when sown at the same time in rainfed environments in southern Australia. To determine reasons for these differences, cultivars of each species were grown at five field sites and variation in their phenology and both pre- and post-anthesis growth was measured. Barley achieved a higher yield of grain and biomass in a shorter duration than the other species. It reached physiological maturity about 10 days (180 thermal units) before the other species, and reached double ridge and anthesis earlier. Triticale was also earlier to reach double ridge and terminal spikelet than the mean for the other species, although it had a similar physiological maturity to the wheats. Barley and triticale developed a greater leaf area and dry mass faster than the wheats and oats. The differences in leaf area was established from the time the first leaf had fully expanded. Barley also developed mainstem leaves and tillers faster than the other species whereas triticale was slower in this respect. Crop growth rate was greatest in barley and triticale up to anthesis, but no differences between species were found in their relative growth rates. The growth rate of individual grains and of total grain per unit ground area were substantially greater in barley than the other species. Oats and durum wheat had the slowest individual grain and total grain

42 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

43 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

44 I. McDonald, G.K., Sutton, B.G. and Ellison, F.W. (1984). Aust. J. Exp. Agric. Anim. Husb. 24, 236–243.

45 Golding, J. B. Restricted tillering in triticale cv. currency-an impediment to grain yield? http://www.regional.org.au/au/asa/1989/contributed/crop/p1-20.htm

growth rates. Grain growth rate per unit ground area was significantly associated with grain yield at one site where this was examined. The change in stem mass between anthesis and physiological maturity, which was determined to assess the possible contribution of stem reserves to grain, was also positively associated with grain yield at the two sites where it was determined, and more so at the drier site. The change in stem mass averaged 76 g m^{-2} at the two sites and this represented 25% of the total grain yield. However, the range varied from 13 to 39% of grain yield (corrected for husk mass in barley and oats). The loss in leaf sheath mass averaged 68 g m^{-2} at both sites; this was not associated with grain yield. [46]

Anthesis generally occurrs 14 days after apical spikelet emergence for triticale. [47]

Early research explored the physiological maturity in seeds of two triticale cultivars. Maximum germination, dry weight, and seedling vigour were attained 24 to 26 days after anthesis. Some seeds were capable of germination 8 days after anthesis. Moisture content decreased slowly from over 78 to 41% at which time functional maturity was attained. After this stage loss of moisture was accelerated and the seed entered into the ripening phase. [48]

In dry springs triticale yields are 10–15 per cent below wheat, due to triticale's longer grain filling period. Triticale usually flowers earlier than wheat planted at a similar time, however grain filling takes longer and grain size may suffer in a hot dry finish (Photo 9). [49]

Photo 9: *Triticale flowering (left) before grain fill (right).*

Source: KT Farmlife and Living Crop Museum

46 López-Castañeda, C., & Richards, R. A. (1994). Variation in temperate cereals in rainfed environments II. Phasic development and growth. *Field Crops Research*, *37*(1), 63–75.

47 Tshewang S. (2011). Frost tolerance in Triticale and other winter cereals at flowering. https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

48 Bishnoi, U. R. (1974). Physiological Maturity of Seeds in Triticale hexaploid L. *Crop Science*, *14*(6), 819–821.

49 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

Nutrition and fertiliser

Key messages

- In nutrient deficient soils, triticale appears to respond better to applied fertilisers than other cereals. Triticale has the capacity to survive by utilising trace elements in soils which would be considered nutrient deficient for any other type of crop. However, growth and yield of triticale is very responsive to phosphorus and nitrogen. [1]
- Triticale has higher nutrient uptake efficiency than other crops. [2]
- The nutrition requirements of triticale are similar to wheat. Triticale is very responsive to high inputs of seed and fertiliser. Adequate fertiliser is needed to achieve protein levels above 10%. [3]
- Triticale has similar phosphorus and nitrogen requirements as wheat and responds to most compound fertilisers.
- In southern Australia high rates of fertiliser applied to triticale on sandy country have resulted in increased yields. [4]
- Most soils in Western Australia (WA) are naturally deficient in the trace elements copper (Cu), zinc (Zn), manganese (Mn) and molybdenum (Mo).
- Triticale grows productively on alkaline soils where certain trace elements are deficient for other cereals. [5]

Triticale has a very extensive root system and can mine the soil more efficiently in conditions where fertility is poor (Photo 1). In general, triticale will respond favourable to cultural practices commonly used for the parental species wheat. However, it has been found that grain biomass and yield response of triticale are substantially higher under larger increments of nitrogen and phosphorus inputs. [6]

High yields in any crop are strongly dependent on adequate nutrients being available during growth.

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

2 Mergoum *et al*. 2004 – in Tshewang S. (2011). Frost tolerance in Triticale and other winter cereals at flowering. https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

3 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

4 Birchip Cropping Group. (2004). Triticale agronomy – 2004. http://www.farmtrials.com.au/trial/13801

5 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

6 Tshewang S. (2011). Frost tolerance in Triticale and other winter cereals at flowering. https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

Photo 1: *Above and below ground growth showing extensive root system.*

Source: Veg trials.

5.1.1 Declining soil fertility

The natural fertility of cropped agricultural soils is declining over time (Photo 2). Grain growers must continually review their management programs to ensure the long-term sustainability of high-quality grain production. Pasture leys, legume rotations and fertilisers all play an important role in maintaining the chemical, biological and physical fertility of soils.

Paddock records, including yield and protein levels, fertiliser test strips, crop monitoring, and soil and plant tissue tests all assist in the formulation of an efficient cropping program. Although crop rotations with grain legumes and ley pastures play an important role in maintaining and improving soil fertility, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed.

The yield potential of a crop will be limited by any nutrient the soil cannot adequately supply. Poor crop response to one nutrient is often linked to a deficiency in another nutrient. Sometimes, poor crop response can also be linked to acidity, sodicity or salinity, pathogens, or a lack of beneficial soil microorganisms. [7]

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

Photo 2: *Cereal plants growing in paddock with low soil fertility.*

Source: FAO

Balancing nutrition

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

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

5.1.2 Fertilisers

Successful fertiliser decisions require robust information about a crop's likely yield response to applied fertiliser in a specific soil type, paddock history and season.

Triticale has similar phosphorus and nitrogen requirements as wheat and responds to most compound fertilisers. As with most crops, rates of fertiliser application should be based on soil testing and other historical response information as well as anticipated costs and returns.

It is also valuable to know the anticipated market for the grain and whether price gradients may reward higher protein levels. This may warrant extra nitrogen usage. [9]

Trials in NSW tested the response of triticale varieties to N and P application. Soil tests indicated marked differences between the years in nitrogen (N) and phosphorus (P) status. In 2002 the site had a very low soil N level (2ug/g nitrate) and a low/medium level of P (16ug/g available P). The data from the 2004 site indicated much higher levels of nutrients, being 64ug/g nitrate and 46ug/g phosphorus.

Although this experiment in 2004 used varieties that have now been largely superseded, the major findings from these experiments were that in a high rainfall region with yield potential levels above average the yield responses to N fertiliser of a range of triticale varieties was at least equal to those for wheat (Table 1). With high yield potential (up to 8 t/ha) triticale varieties showed up to 4 times the yield response of the wheat variety Janz. At lower yields levels (2 t/ha) there were no differences in response between wheat and triticale varieties.

Table 1: *Response of triticale (tonne/ha) to nitrogen fertiliser.*

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

9 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

Variety	0 nitrogen	50 kg/ha nitrogen	100 kg/ha nitrogen	Response 100 kg/ha nitrogen
Everest	6.85	7.96	7.98	1.13
Kosciusko	7.37	7.48	8.34	0.97
Tahara	7.96	8.22	8.52	0.56
Janz wheat	6.73	6.99	7.00	0.27

These results indicated that, with low/medium yield expectations, wheat and triticale appear to show similar responses to additional N fertiliser. In locations with increased yield potential there is a suggestion that N requirements of triticale varieties exceed those of bread wheat varieties. The exact amounts of additional N fertiliser applied will depend on expected grain yields, soil N status, crop water availability and the current ratio of N fertiliser prices and crop returns.

Growers need to aim for sufficient soil N to obtain 11.5% protein in triticale as below this level both grain yield and protein will be reduced. This aspect of triticale has been overlooked in the past and often triticale yields have been severely reduced compared with those in wheat as a result of inadequate N fertiliser application. [10]

A productive triticale will require application of phosphorous (P) and nitrogen (N) at sowing. Additional nitrogen is likely to be required for maximum dry matter production for grazing and grain yield, particularly if the crop has been grazed. Consider applying 15—20 kg P per ha at sowing. This is equivalent to 75—100 kg MAP per ha which will also include 7.5—10 kg N per ha. A triticale used for grazing as well as grain production will require significant N. If targeting 3 t per ha then a minimum of 69 kg N per ha should be applied just to cover removal. If grazing is also included or soil nitrogen levels are low, additional N should be applied. Application can be split between sowing and top-dressing post-grazing or during stem elongation stage (soon after Zadoks 31).

Paddocks with a history of legume dominant pasture or a pulse crop (e.g. lupins, field peas) tend to have a higher N status than those with a history of grassy pasture or cereal and canola crops and will not need as much applied N. [11]

Table 2 lists the concentration of nitrogen and phosphorous in common fertilisers. Use this to calculate total quantity of fertiliser to apply. In the example with a requirement of 69 kg N per ha this could be achieved by applying:

- 100 kg MAP per ha or 10 kg N per ha, plus
- 130 kg urea per ha or 59.8 kg N per ha supplying a total of 69 kg N per ha for the season.

10 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

11 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

Table 2: *Nitrogen and phosphorous content of common high analysis fertilisers.*

Product	Phosphorus		Nitrogen	
	Kg/kg product	Kg/100 kg product	Kg/kg product	Kg/100 kg product
MAP	2.2	22	1.0	10
DAP	2.0	20	1.8	18
Urea	0	0	4.6	46

Source: Waratah Seed Co

MORE INFORMATION

Fertilising for grazing cereals

Crop Nutrition: region by region

In a field experiment conducted in India, nine combinations of nitrogen (N) and phosphorus (P) were factorially randomised with four triticales and one check each of wheat and rye to investigate the effect of progressive rates of application (180–300 kg N+P ha^{-1}) of combined N+P fertiliser on grain yield and quality. Grain yield, protein content, and values for yield components significantly increased with increasing combined N+P fertiliser rates up to 240 kg N+P ha^{-1} (200 kg N+40 kg P ha^{-1}). The response of further increases in N+P rates gradually diminished, thereafter, despite increasing N and/or P in the fertiliser combinations. This research revealed the harmful effects of overfertilisation. This was thought to be due to a decrease in the activity of the enzyme despite increasing N and/or P in the fertiliser combinations. [12]

Application

Stage: Pre Plant (or) At Planting

Rate: 250–400 kg/Ha (Dryland), 500–750 kg/Ha (Irrigated)

Product: Standard Pellets, Organic Complete (or) Growers Special

Application Method

Apply by using either gravity feed openers or air drills to sub-surface band the fertiliser 5 cm (2") below or to the side of the seed.

Application Considerations

Use higher rates where nitrogen is known to be deficient, when double cropping or with large amounts of undecomposed stubble.

Rates should be reduced by 50% for very sandy soils and may be increased by 30% for heavy textured soils or where soil moisture conditions at planting are excellent.

Rates should be reduced by 50% when planting equipment with narrow slit openers is used (the fertiliser concentration is increased around the seed).

Rates may be increased by 50% when air seeders are used operating at high pressures with wide openers. Air seeders spread the fertiliser bands when operating at high pressures reducing the fertiliser concentration around the seed. [13]

5.1.3 Fungi and soil health

Arbuscular Mycorrhizal (AMF, previously known as VAM) is a fungus that penetrates the roots of a vascular plant in order to help them to capture nutrients from the soil. These fungi are scientifically well known for their ability to uptake and transport mineral nutrients from the soil directly into host plant roots. Approximately 80% of known plant species, including most economically important crops, have a known symbiosis with them.

The microscopic fungal fibres vastly extend the root system. They extract water and nutrients from a large volume of surrounding soil, and bring them to the plant, improving nutrition and growth. A plant's root system, however big, can never be as

12 Moinuddin, S., & Afridi, M. M. R. K. (1997). Grain yield and quality of triticale as affected by progressive application rates of nitrogen and phosphorus fertiliser. *Journal of plant nutrition*, *20*(4–5), 593–600.

13 DinoFert. (2016). Triticale. http://www.dinofert.com.au/technical-information/plant-nutrition-guide/item/149-triticale

extensive as the network of fungal fibres. The microscopic filaments grow through the soil and reach much more nutrients than the roots would.

In cropping systems, most plants are mycorrhizal and depend, to varying degrees, on these fungi to supply them with nutrients such as phosphorus and zinc. In turn, the plant hosts the fungus and supplies it with carbohydrates.

This mutually beneficial partnership between plants and soil fungi has existed as long as there have been plants growing in soil. Unfortunately, these beneficial mycorrhizal fungi are destroyed in the development of human-made landscapes, causing vegetation in these environments to struggle.

Unlike saprobic soil fungi, which colonise and break down organic matter and do not require a host plant in the system to complete their lifecycle, arbuscular mycorrhizal fungi (AMF), the type found in cropping systems, do require the presence of a host to reproduce and are therefore called obligate symbionts. They produce spores as a means of survival in soil during the absence of a host (e.g. a clean fallow) and then germinate and colonise host roots. The longer the fallow, the less chance of survival of these spores and this is the cause of the syndrome that is called 'Long Fallow Disorder' (LFD). Hyphae in soil or in roots in the soil may also grow to new roots however they survive for less time in the soil than the spores.

AMF levels can be severely reduced by long periods of fallow, such as those induced by drought, or the growth of non-host crops. Knowledge of the P and Zn levels in your soil and supplementation with fertiliser if required could avoid unexpected yield reduction due to nutrient deficiencies.

Primarily, LFD is a phosphorus or zinc deficiency of the plant and can be overcome by the application of P and/or Zn fertilisers. Having adequate populations of mycorrhizal fungi present in soils therefore can be beneficial and in some cases essential for crop growth. Without mycorrhizae, much higher amounts of P and/or Zn fertiliser are required to attain the same level of productivity as when plants are mycorrhizal.

When reintroduced to the soil, the mycorrhiza colonizes the root system, forming a vast network of filaments. This fungal system retains moisture while producing powerful enzymes that naturally unlock mineral nutrients in the soil for natural root absorption.

Maintaining high mycorrhizal populations promotes good crop growth and the efficient use of P and Zn fertilisers. Many crop species require only half the phosphate concentration in soil when they are colonised by AMF as they do without AMF for the same level of production. [14]

The colonisation of rye roots with vesicular-arbuscular (VA) mycorrhizal fungi was investigated at two sites, cultivated using conventional or biological-dynamic farming methods. The VAM infection rate and infected root length were significantly higher at the biologically-dynamic cultivated site. It is suggested that these differences are due to several factors, such as the use of fertilisers and agro-chemicals, and the influence of crop rotation. [15]

Management to optimize mycorrhizae

If you suspect low *AM*:

- Grow crops with low or very low mycorrhizal dependency eg wheat or barley – they won't suffer much yield loss but will still increase the AM inoculum for following crops.
- Avoid non-mycorrhizal crops, as they will not increase AMF inoculum status.
- If you wish to grow a crop of high mycorrhizal dependency for reasons such as good price, apply high rates of P and Zn fertilisers.

14 Seymour N. (2009). GRDC Update Papers: Mycorrhizae and their influence on P nutrition. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2009/09/mycorrhizae-and-their-influence-on-p-nutrition

15 Sattelmacher, B., Reinhard, S., & Pomikalko, A. (1991). Differences in Mycorrhizal Colonization of Rye (Secale cereale L.) Grown in Conventional or Organic (Biological-dynamic) Farming Systems. *Journal of Agronomy and Crop Science*, *167*(5), 350–355.

- Adopt zero or reduced tillage practices during fallow periods, as this is less harmful to AMF than frequent tillage. [16]

5.1 Crop removal rates

Each tonne of triticale harvested will remove approximately 23 kg N per ha from the paddock (Table 3). So, if targeting 3 t per ha then a minimum of 69 kg N per ha should be applied just to cover removal. If grazing is also included or soil nitrogen levels are low, additional N should be applied.

Table 3: *Nutrients removed (kg) per tonne of grain production.*

Crop type	Nitrogen	Phosphorus	Potassium	Sulfur
Wheat	21	3.0	5	1.5
Triticale	21	3.0	5	1.5
Barley	20	2.7	5	1.5
Oats	17	2.5	4	1.5

Source: Agriculture Victoria

5.2 Soil testing

Key points:

- A range of soil test values used to determine if a nutrient is deficient or adequate is termed a critical range.
- Revised critical soil test values and ranges have been established for combinations of nutrients, crops and soil.
- A single database collated more than 1892 trials from Western Australia for different crops.
- Nutrient sufficiency is indicated if the test value is above the critical range.
- Where the soil test falls below the critical range there is likely to be a crop yield response from added nutrients.
- Critical soil test ranges have been established for 0 to 10 cm and 0 to 30 cm of soil.
- Soil sampling to greater depth is considered important for more mobile nutrients (N, K and S) as well as for pH and salinity.
- Use local data and support services to help integrate critical soil test data into profitable fertiliser decisions.

Accurate soil tests allow landholders to maximise the health of their soils and make sound decisions about fertiliser management to ensure crops and pastures are as productive as possible. Up-to-date critical soil test values will help improve test interpretation to inform better fertiliser decisions. Identifying potential soil limitations enables landholders to develop an action plan (such as an appropriate fertiliser program) to reduce the potential of 'problem' paddocks. [17]

In Western Australia, profitable grain production depends on applied fertiliser, particularly nitrogen (N) phosphorus (P), potassium (K) and sulfur (S). Fertiliser is a major variable cost for grain growers. Crop nutrition is also a major determinant of profit. Both under and over-fertilisation can lead to economic losses due to unrealised potential or wasted inputs.

Before deciding how much fertiliser to apply, it is important to understand the quantities of available nutrients in the soil and where they are located in the soil

16 Seymour N. (2009). GRDC Update Papers: Mycorrhizae and their influence on P nutrition. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2009/09/mycorrhizae-and-their-influence-on-p-nutrition

17 DAFWA. (2016). Soil sampling and testing on a small property. https://www.agric.wa.gov.au/small-landholders-western-australia/soil-sampling-and-testing-small-property

profile. It is also important to consider whether the fertiliser strategy aims to build, maintain or mine the soil reserves of a particular nutrient.

Soil test critical values indicate if the crop is likely to respond to added fertiliser, but these figures do not predict optimum fertiliser rates. Soil test results can be compared against critical nutrient values and ranges, which indicate nutrients that are limiting or adequate.

When considered in combination with information about potential yield, last year's nutrient removal and soil type, soil tests can help in making fertiliser decisions.

Principal reasons for soil testing for nutrition include:

- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity) and salinity, which affect the availability of nutrients to crops;
- zoning paddocks for variable application rates;
- comparing areas of varying production; and
- as a diagnostic tool, to identify reasons for poor plant performance.

Soil acidity or alkalinity can influence the amount of nutrients available to plants. Table 4 demonstrates nutrient constraints based on soil pH.

Table 4: *Soil classifications for pH (1:5 soil:water).*

Increasing acidity						**Increasing alkalinity**	
Acidic				**Neutral**	**Alkaline**		
3	4	5	6	7	8	9	10
Toxicity of :						Toxicity of :	
Aluminium (Al)			**Ideal pH Range** for plant growth			Sodium (Na)	
Manganese (Mn)						Boron (Bo)	
Iron (Fe)						Bicarbonate (HCO3)	
Deficiency of:						Deficiency of:	
Magnesium (Mg)						Fe	
Calcium (Ca)						Zinc (Zn)	
Potassium (K)						Mn	
Phosphorus (P)						Copper (Cu)	
Molybdenum (Mo)						P	

Source: DAFWA

Why Test Soil?

Soils can be tested for a range of reasons. For example, to estimate how much water can be stored, to identify the depth of root barriers or subsoil constraints (such as acidity, high aluminium, high levels of boron or salinity) and to quantify the potential occurrence of a soil-borne disease.

Principal reasons for soil testing for nutrition include:

- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity) and salinity, which affect the crop demand as well as the ability to access nutrients;
- zoning paddocks for variable application rates; and

MORE INFORMATION

Soil Nutrient testing: How to get meaningful results.

Soil testing for crop nutrition – Western region factsheet.

- as a diagnostic tool, to identify reasons for poor plant performance. Soil test results are part of the information that support decisions about fertiliser rate, timing and placement.

To determine micronutrient status, plant tissue testing is usually more reliable. [18]

Basic Requirements

There are three basic steps that must be followed if meaningful results are to be obtained from soil testing. These are:

1. To take a representative sample of soil for analysis,
2. To analyse the soil using the accepted procedures that have been calibrated against fertiliser experiments in that particular region and
3. To interpret the results using criteria derived from those calibration experiments.

Each of these steps may be under the control of a different person or entity. For example, the sample may be taken by the farmer manager or by a consultant agronomist; it is then sent to an analytical laboratory; and finally the soil test results are interpreted by an agronomist to develop recommendations for the farmer. [19]

5.2.1 Types of test

Appropriate soil tests for measuring soil extractable or plant available nutrients are:

- bicarbonate extractable P (Colwell-P);
- bicarbonate extractable K (Colwell-K);
- KCl-40 extractable S; and
- 2M KCl extractable inorganic N, which provides measurement of nitrate-N and ammonium-N.

For determining crop N requirement, soil testing is unreliable. This is because soil nitrogen availability and crop demand for nitrogen are both highly influenced by seasonal conditions.

Other measurements that aid the interpretation of soil nutrient tests include soil pH, percentage of gravel in the soil, soil carbon/organic matter content, P sorption capacity [currently measured as Phosphorus Buffering Index (PBI)], electrical conductivity, chloride and exchangeable cations (CEC) including aluminium. [20]

Depth for nutrient sampling

The Better Fertiliser Decisions for Cropping (BFDC) project has highlighted that deeper soil sampling provides more appropriate critical soil values and ranges for many soil types in WA. Soil sampling depth for nutrient analysis is currently 0 to 10 centimetres. The 0 to 10 cm soil layer was originally chosen because nutrients, especially P, and plants roots are concentrated within this layer. Increasingly, there is evidence of the need to assess production constraints, including acidity, in both the surface soil and subsoil layers.

The importance of subsoil K and S contributions to plant nutrient uptake has also been known for a long time. To obtain more comprehensive soil data, including nutrient data, sampling to 30 cm should be considered, providing there are no subsoil constraints (Photo 3). Collecting deeper soil samples does raise issues of logistics and cost, which should be discussed with soil test providers. One suggested approach is to run a comprehensive suite of soil tests on all 0 to 10 cm samples and only test for N, K, S and salinity in 10 to 30 cm samples. On sands, P can also be tested for at depth.

18 GRDC (2014). Crop nutrition: Soil testing for crop nutrition – western region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-west

19 Loch D. Soil nutrient testing: how to get meaningful results. https://www.daf.qld.gov.au/__data/assets/pdf_file/0006/65985/Soil-Nutrient-Testing.pdf

20 GRDC (2014). Crop nutrition: Soil testing for crop nutrition – western region Factsheet. www.grdc.com.au/GRDC-FS-SoilTestingW

Note that pH samples need to be taken at 10 cm increments to depth. If sampling to 30 cm, the 0 to 10 cm, 10 to 20 cm and 20 to 30 cm soil layer samples should be tested for pH so that soil acidity can be better understood.

Photo 3: *Nutrients, even relatively immobile ones such as phosphorus (P), can move down the profile in sandy soil, so testing nutrient reserves to depth can be useful.*

Source: GRDC, Photo: Gavin Sarre

Collecting soil samples for nutrient testing

The greatest source of error in any soil test comes from the soil sample. Detailed sampling instructions are usually provided in soil test kits. The following information is provided as a reference only.

When sampling the 0 to 10 cm soil layer, 20 to 30 cores per site are required, while for the 10 to 30 cm soil layer, 8 to 10 cores per site are required. Cores per sample from a uniform zone should be bulked, mixed and sub-sampled for testing. For pH, it is often more useful to see how the figures vary within the paddock or across soil types – therefore sampling will always be less than ideal. For pH, 8 to 10 cores bulked from six locations in a paddock is usually adequate.

To ensure that a sample is representative:

- check that the soil type and plant growth where the sample is collected are typical of the whole area;
- 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;
- avoid shortcuts in sampling such as taking only one or two cores, a handful or a spadeful of soil; and
- avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers or other sources of nutrients such as sunscreen, containing zinc.

Critical values and ranges

A soil test critical value is the soil test value required to achieve 90% of crop yield potential. The critical range around the critical value indicates the reliability of the test. The narrower the range the more reliable the data (Table 5 and 6).

Table 5: *Summary table of critical values (mg/kg) and critical ranges for the 0–10 cm sampling layer:*

Nutrient	Crop	Soil Types	Critical values (mg/kg)	Critical range (mg/kg)
P	Wheat	Grey sands	14	13–16
		Other Soils	23	22–24
		Grey sands in Northern Region	9	6–12
		Yellow sands in Northern Region	22	21–23
		Grey sands in Southern Region	12	10–15
		Yellow Sands in Southern Region	30	25–37
	Canola	All	19	17–25
K	Wheat	All	41	39–45
		Yellow sands	44	34–57
		Loams	49	45–52
		Duplexes	41	37–44
	Lupins	Grey Sands	25	22–28
	Canola	All	44	42–45
S	Wheat	All	4.5	3.5–5.9
	Lupins	All	n/a	N/A
	Canola	All	6.8	6.0–7.7

Source DAFWA in GRDC

Table 6: *Summary table of critical values (mg/kg and kg/ha) and critical ranges for the 0–30 cm sampling layer.*

Nutrient	Crop	Critical values (mg/kg)	Critical range (mg/kg)
P	Wheat	11	10–11
	Lupins	9	8–10
	Canola	N/A	N/A
K	Wheat	N/A	N/A
	Lupins	N/A	N/A
	Canola	31	28–34
S	Wheat	4.6	4.0–5.3
	Lupins	N/A	N/A
	Canola	7.1	6.7–7.5

Source DAFWA and Murdoch University in GRDC.

The critical value indicates if a nutrient is likely to limit crop yield based on whether the value is greater than or less than the upper or lower critical range value (Figure 1). If the soil test value is less than the lower limit, the site is likely to respond to an application of the nutrient. For values within the range there is less certainty about whether a response will occur. In this case, growers have to exercise judgement about the costs and benefits of adding fertiliser in the forthcoming season, versus those associated with not applying. If the soil test is above the critical range, fertiliser is applied only to maintain soil levels or to lower the risk of encountering deficiency. The larger the range around the critical value, the lower the accuracy of the critical value. [21]

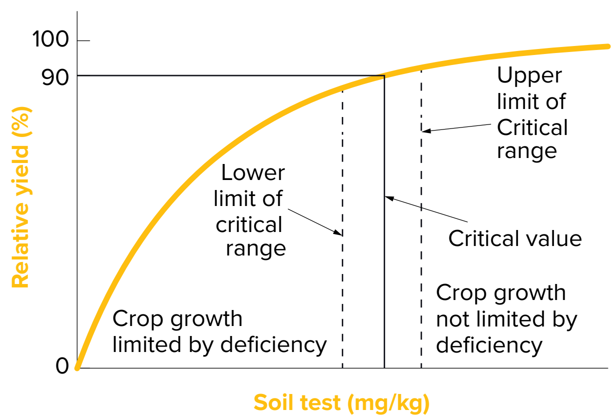


Figure 1: *Generalised soil test response calculation curve. A generalised soil test–crop response relationship defining the relationship between soil test value and per cent grain yield expected. A critical value and critical range are defined from this relationship. The relative yield is the unfertilised yield divided by maximum yield, expressed as a percentage. The BFDC Interrogator fits these curves and estimates critical value and critical range. Normally 90 per cent of maximum yield is used to define the critical value but critical values and ranges at 80 per cent and 95 per cent of maximum yield can also be produced.*

Source: DAFWA, Murdoch University in GRDC

21 GRDC. (2014). Crop Nutrition Fact Sheet – Western Region. Soil Testing for crop nutrition. www.grdc.com.au/GRDC-FS-SoilTestingW

5.2.2 West Australian Soil Quality Program

Key Points

- Soil quality is currently being measured in grain-producing areas across Australia.
- This monitoring program and associated website www.soilquality.org.au provide the Australian grains industry with a unique resource on soil quality including soil biology, chemistry and physics.
- Each grower's soil quality information is housed on the soil quality website and workshops provide growers with training to access and interpret this information to support improved soil management.

www.soilquality.org.au provides an, interactive resource to the Australian grains industry on soil quality, including soil biology as well as soil chemistry and physics. The web site allows growers to benchmark their paddocks against values for their local catchment and region as well as against expert opinion. This information aids growers to determine if they are heading in the right direction with their systems and practices and supports growers to improve soil management practices. The Soil Quality Monitoring Program and the web site www.soilquality.org.au are expanding to include grainproducing areas across Australia. This will give growers across Australia access to regionally specific data on soil biological, chemical and physical constraints to production. This will aid the Australian grains industry to make better management decisions. [22]

5.3 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.

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.

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'S

- Sample the correct plant part at the specified time or growth stage.
- Use clean plastic disposable gloves to sample to avoid contamination.

22 Soilquality.org. Western Australian Soil quality program. http://www.soilquality.org.au/factsheets/w-a-soil-quality-program

- 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 despatched to the laboratory immediately, to arrive before the weekend.
- Generally sample in the morning while plants are actively transpiring.

DON'TS

- 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[23]

Table 7: *Plant tissue requirements for nutrient testing.*

Crop	Growth Stage to sample	Plant Part	Number required
Triticale	Seedling to early tillering (GS 14 -21)	Whole tops cut off 1 cm above ground	40
	Early tillering to 1st 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 1st node (GS21-31)	Youngest expanded blade (YEB) plus next 2 lower blades.	40

Source: BackPaddock

5.4 Nitrogen

Key points:

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

23 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

- Soil testing and nitrogen models will help determine seasonal nitrogen requirements.
- Some farmers believe that triticale produces more grain under the same amount of applied nitrogen in wheat and barley. [24]

The two forms of soil mineral N absorbed by most plants are nitrate (NO3N) and ammonium (NHþ4N) (Figure 2). In well-aerated soils during the growing season NO3N becomes the main form of N available for crops as microbial activity quickly transforms NHþ4N into NO3N. It is crucial to keep the NO3N levels at an adequate level because, on one hand, too low levels of soil NO3N can limit crop production and, on the other hand, too high amounts of NO3N can lead to environmental pollution. The levels of soil NO3N vary across space and over time. Proper agricultural management needs to consider both site-specific variations as well as temporal patterns in soil NO3N to supply optimum amounts from both organic and mineral sources. [25]

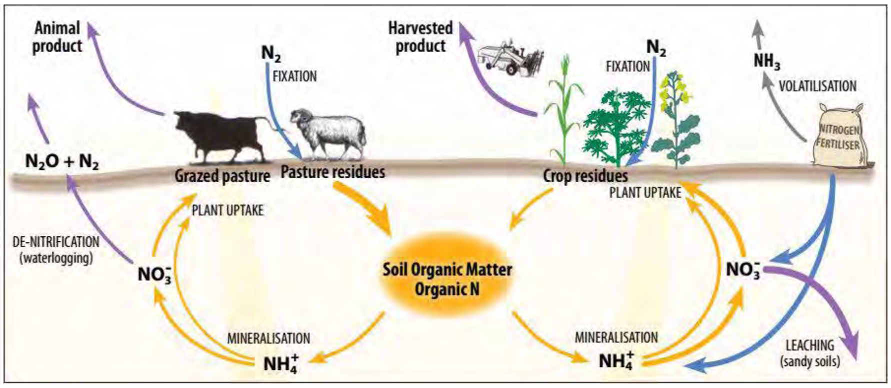


Figure 2: *Principle nitrogen cycling pathways in a mixed cropping/pasture system (adapted from Peverill et al. 1995).*

Source: Soilquality.org

Give particular attention to nitrogen supply. Triticale used for grazing and grain could use up to 100 kg/ha of N. Consider applying 60–100 kg/ha of N as a topdressing if soil nitrogen levels are low. Long fallow paddocks following good legume pastures generally have satisfactory nitrogen levels. Long fallow paddocks have the highest yield potential because of stored moisture and have the greatest potential to respond to soil nitrogen. Yield increases are likely when nitrogen is applied to paddocks with low nitrogen status. The contribution of pulse crops and pastures to soil nitrogen depends on the amount of plant material produced and/or the subsequent grain yield. The actual amount of soil nitrogen accumulated is highly variable. [26]

Triticale has been found to response well to nitrogen application under drought conditions (Figure 3). [27]

24 Ground Cover Issue 59 – Triticale. 1/01/2006. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-59/Triticale

25 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.

26 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

27 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

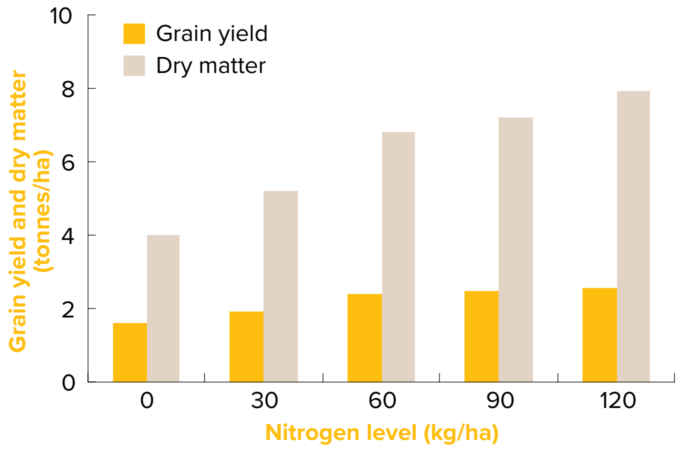


Figure 3: *Triticale grain yield and straw dry-matter response to nitrogen levels under drought conditions in Morocco.* [28]

Trials in Europe found that a N 90–120 rate to be economically and ecologically optimal for spring triticale. It resulted in the highest (4.81–4.92 Mg/ha^{-1}) grain yield. [29]

Additional nitrogen is likely to be required for maximum grain yield, particularly if the crop has been grazed.

IN FOCUS

Responses of triticale, wheat, rye and barley to nitrogen fertiliser

A hexaploid triticale from Mexico and local cultivars of wheat, rye and barley, each at five levels of fertiliser nitrogen (0, 35, 70, 105 and 140 kg N/ha) with four replications, were grown in a field experiment in South Australia. A visually discernible response to nitrogen fertiliser by all four genotypes from an early stage was confirmed by quantitative sampling at tiliering, anthesis and maturity. Responses in plant dry weight to 105 kg N/ha were maintained until anthesis but grain yield responses were significant only at 35 kg N/ha. Total dry matter production responses at maturity to more than 35 kg N/ha were small. Numbers of tillers and heads were increased by nitrogen additions up to 140 and 105 kg N/ha, respectively, and plant height measurements showed general increases to 70 kg N/ha with significant lodging at higher nitrogen levels in both rye and triticale. For all genotypes, thousand grain weight decreased with increasing level of nitrogen supply while grain and straw nitrogen increased up to levels of 140 and 105 kg N/ha, respectively. Nitrogen supply had little effect on maturity, plants at 0 and 140 kg N/ha reaching anthesis less than a day apart. The lack of a significant nitrogen x genotype interaction in nearly all the data suggests that the triticale does not differ in its nitrogen nutrition from the traditional cereals. Triticale consistently outyielded the other cereals in total dry matter production followed by the rye, wheat and barley in that order. Grain yield was highest in the wheat and least in the rye, the latter also being the least responsive to nitrogen.

28 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

29 Janušauskaitė, D. (2013). Spring triticale yield formation and nitrogen use efficiency as affected by nitrogen rate and its splitting. *Zemdirbyste-Agriculture*, *100*(4), 383–392.

The advantage of the triticale lay in its high grain protein and lysine content combined with good yield. [30]

Pre-plant N increased forage production and frequently produced more boot stage triticale biomass. It also tended to increase P uptake, but reduced P and forage protein concentrations likely due to plant dilution. [31]

Trials outside Canberra exploring crop management of dual purpose cereals suggest that Nitrogen should be applied at sowing to ensure good early plant growth and the build-up of a feedbank. Post-sowing nitrogen application should be left until after grazing and should not be applied just before grazing due to the risk of high forage nitrate levels. High nitrate in forage can lead to nitrite toxicity in grazing livestock, especially under cool, cloudy conditions. Growers may safely apply 50 kilograms of nitrogen per hectare as urea immediately after grazing finishes to boost plant recovery. [32]

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. However, in most of the newer varieties lodging is not considered a problem. The likelihood of lodging is increased by high rates of nitrogen fertiliser and under irrigated conditions. [33]

5.4.1 Nitrogen deficiency symptoms in cereals

What to look for

Paddock

- Light green to yellow plants particularly on sandy soils or unburnt header or swathe rows (Photo 4).
- Double sown areas have less symptoms if nitrogen fertiliser was applied at seeding.

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 (Photo 5).
- Other leaves start to yellow and oldest leaves change from yellow to almost white.
- 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.

30 Graham, R. D., Geytenbeek, P. E., & Radcliffe, B. C. (1983). Responses of triticale, wheat, rye and barley to nitrogen fertiliser. *Animal Production Science*, *23*(120), 73–79.

31 Brown, B. (2011). Nitrogen Timing for Boot Stage Triticale Forage Yield and Phosphorus Uptake. *Forage and Grazinglands*, *9*(1), 0–0.

32 Lush D. (2014). Ground Cover Issue 109: Mar-Apr 2014. Rules of thumb for grazing cereals. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-109-Mar-Apr-2014/Rules-of-thumb-for-grazing-cereals

33 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Photo 4: *Nitrogen deficiency on unburnt header row.*

Source: DAFWA

Photo 5: *Deficient plants are smaller with yellow leaves and fewer tillers.*

Source: DAFWA

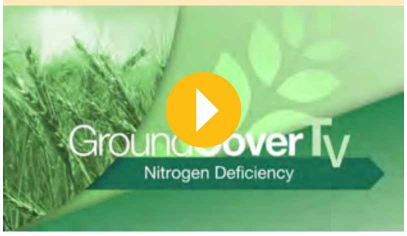
What else could it be?

Condition	Similarities	Differences
Diagnosing waterlogging in cereals	Pale plants with oldest leaves most affected	Root browning or lack of feeder roots and wet soil
Diagnosing potassium deficiency in wheat	Pale plants with oldest leaves most affected	Differences include more marked leaf tip death and contrast between yellow and green sections of potassium deficient plants. Tillering is less affected.
Diagnosing molybdenum deficiency in cereals	Pale poorly tillered plants	Molybdenum deficiency affects the middle leaves first and cause white heads, shrivelled grain and delayed maturity

Deficiency symptoms can be treated with Nitrogen fertiliser or foliar spray. NOTE: There is a risk of volatilisation loss from urea or (ammonium sources of nitrogen on alkaline soils) when topdressesd on dry soils in dewy conditions. Losses rarely exceed 3% per day. [34]

VIDEOS

WATCH: GCTV14: Nitrogen deficiency.



34 DAFWA. Diagnosing Nitrogen deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-wheat

5.4.2 Managing nitrogen

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 chances 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. [35]

Nitrogen fertilisers are a significant expense for broadacre farmers so optimising use of fertiliser inputs can reduce this cost. There are four main sources of nitrogen available to crops: stable organic nitrogen, rotational nitrogen, ammonium and nitrate. To optimise plants' ability to use soil nitrogen, growers should first be aware of how much of each source there is. The best method of measuring these nitrogen sources is soil testing.

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 nitrogen during crop emergence and establishment is critical. Nitrogen use efficiency can be improved by delaying fertiliser application until the crop's roots system is adequately developed. This can be 3–4 weeks after germination.

Later nitrogen 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 nitrogen will be achieved. An advantage of late applications (1st node visible) is that growers have a better idea of yield potential before applying the nitrogen. [36]

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 8 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 134 kg N/ha.

Clearly predicting yield during the growing season is crucial to allow growers to make tactical decisions on N management. Recent experience 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. [37]

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

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

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

Table 8: *Nitrogen 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
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

5.5 Phosphorus

Key Points

- Phosphorus (P) is one of the most critical and limiting nutrients in agriculture in Australia.
- Phosphorous cycling in soils is complex.
- Only 5–30% of phosphorus applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus fertiliser is best applied at seeding.
- Compared with bread wheats, triticale and rye have been found to be more efficient in using P at low levels of P supply.
- Triticale has been classified as phosphorus efficient (higher yielding under than other cultivars under low phosphorus supply) and/or phosphorus responsive (higher yielding than other cultivars under high phosphorus supply). [38]

After nitrogen stress, phosphorus is the second most widely occurring nutrient deficiency in cereal systems around the world. [39] Phosphorus is essential for plant growth, but few Australian soils have enough phosphorus for sustained crop and pasture production. Many soils have large reserves of total phosphorus, but low levels of available phosphorus. Complex soil processes influence the availability of phosphorus applied to the soil, with many soils able to adsorb or 'fix' phosphorus, making it less available to plants (Figure 4). A soil's ability to fix phosphorus must be measured when determining requirements for crops and pastures. [40]

38 Ortiz-Monasterio, J. I., Pena, R. J., Pfeiffer, W. H., & Hede, A. H. (2002, June). Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In *Proc. of the 5th Int. Triticale Symp., Annex* (Vol. 30).

39 Ortiz-Monasterio, J. I., Pena, R. J., Pfeiffer, W. H., & Hede, A. H. (2002, June). Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In *Proc. of the 5th Int. Triticale Symp., Annex* (Vol. 30).

40 Soilquality.org. Phosphorus NSW. http://www.soilquality.org.au/factsheets/phosphorus-nsw

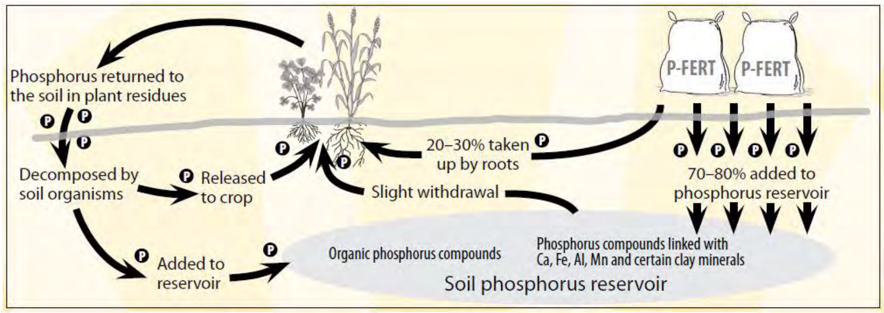


Figure 4: *The phosphorus cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited (from Fertiliser Industry Federation of Australia Inc., 2000).*

Source: Soilquality.org

There has been substantial improvement (e.g., genetic gains) in terms of P responsiveness in triticale, however there has been little improvement in terms of phosphorus use efficiency; i.e. performance under low phosphorus conditions. Research in Mexico found that triticale was responsive to P applications with grain yields in some genotypes almost three times higher in the 80 kg P2O5 application treatment. [41]

Phosphorus application has also been found to influence triticale growth stages. One study found that plots treated with phosphorus (90 kg ha^{-1}) produced more days to anthesis (126), plant height (114 cm) and leaf area cm^2 (21) while more days to physiological maturity (167) was formed by 60 kg P ha^{-1}. [42]

Triticale responds well to phosphorus application under drought conditions (Figure 5). [43]

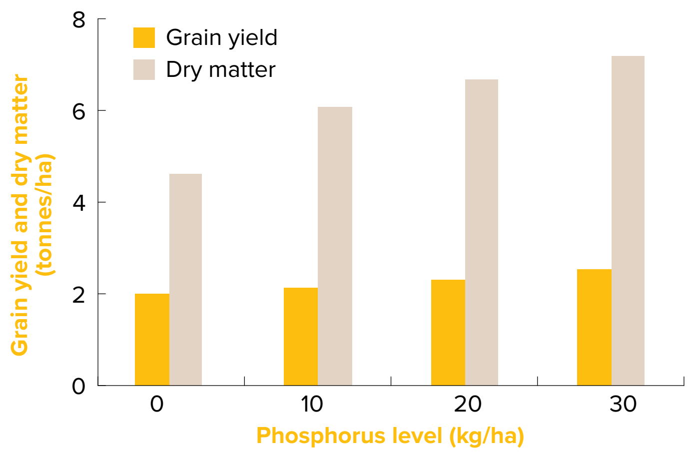


Figure 5: *Triticale grain yield and straw dry-matter response to phosphorus levels under drought conditions in Morocco.* [44]

41 Ortiz-Monasterio, J. I., Pena, R. J., Pfeiffer, W. H., & Hede, A. H. (2002, June). Phosphorus use efficiency, grain yield, and quality of triticale and durum wheat under irrigated conditions. In *Proc. of the 5th Int. Triticale Symp., Annex* (Vol. 30).

42 Iqbal, B., Ahmad, B., Ullah, I., Khan, A. A., Anwar, S., Ali, A., ... & Khan, S. (2016). Effect of phosphorus, sulfur and different irrigation levels on phenological traits of Triticale. *Pure and Applied Biology*, *5*(2), 303.

43 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

44 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

Another study found that, under field conditions, triticale presented higher grain yield response to P than seven wheat cultivars. [45]

A study in south-western Australia found that on an acidic soil, triticale required from 50 to 70% less P than wheat, but on less acidic soil it required 100% more P. [46]

Phosphorus deficiency is thought to be responsible for biomass reduction of triticale in nutrient solution with aluminium. One study suggests that in previous experiments, phosphorus deficiency is probably the most important limiting factor in acid nutrient solutions with Aluminium. [47]

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

5.5.1 Phosphorus in WA

Most soils across the WA wheatbelt now exceed critical levels for soil phosphorus. Modelling work suggests many growers can start to reduce phosphorus inputs without any impact on yields. Some growers are now lowering their phosphorus applications by 20 to 30%. However, any adjustments to phosphorus rates need to be done in relation to soil pH and other production constraints because phosphorus requirements will be higher on acid and non-wetting soils and in areas prone to root disease. The addition of lime to increase soil pH has been found to improve crop response to nutrients such as phosphorus. While most cropping paddocks in the western region have sufficient phosphorus levels, more than three-quarters have surface pH levels that affect grain yield potential. A large number have a subsoil pH below the critical level of 4.8. Once surface soil pH drops below 5.5, phosphorus availability is compromised – even in soils with more than the critical level of phosphorus. The problem is that fixing acid soils is relatively expensive – especially for growers in the eastern WA wheatbelt who operate under very tight profit margins. One recommendation is for growers to divert money they might have spent on phosphorus applications into targeted liming of acid soils to boost yield potential. [48]

5.5.2 Managing phosphorus

Key points:

- After decades of consistent phosphorus (P) application, 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.

45 Ben, J. R. (1991). Response of triticale, wheat, rapeseed and lupine to phosphorus in soil. In *2. Proceedings of the International Triticale Symposium. Passo Fundo (Brazil). 1–5 Oct 1990.*.

46 Bolland, M. D. A. (1992). The phosphorus requirement of different crop species compared with wheat on lateritic soils. *Fertilizer research*, *32*(1), 27–36.

47 Quartin, V. L., Azinheira, H. G., & Nunes, M. A. (2001). Phosphorus deficiency is responsible for biomass reduction of triticale in nutrient solution with aluminum. *Journal of plant nutrition*, *24*(12), 1901–1911.

48 Paterson J. (2014). Dr Craig Scanlon on Soil Acidity and phosphorus in western region. Ground Cover Supplement, Issue 108, January – February 2014.

- Work with an adviser to refine your fertiliser strategy.
- Phosphorus (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 to 30 centimetres) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Applying P at depth (15 to 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 nitrogen (N), to this adjusted yield potential. [49]

MORE INFORMATION

Crop nutrition Phosphorus management Factsheet – Western region.

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. [50]

Phosphorus fertiliser and, where necessary, nitrogen fertiliser are recommended in the same amounts as recommended for wheat.

Mycorrhiza fungi play an important role in plant uptake of phosphorus (P).The P uptake by wheat, rye, and triticale was 10, 64, and 35%, respectively, higher with rather than without mycorrhizal infection. Triticale followed wheat, with similar mycorrhizal dependency. [51]

Symptoms

Paddock

- Smaller, lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows.
- Plants look unusually water-stressed despite adequate environmental conditions (Photo 6).
- Affected areas are more susceptible to leaf diseases.

Plant

- In early development, usually in cases of induced phosphorus deficiency, seedlings appear to be pale olive green and wilted (Photos 7 and 8).
- 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 nitrogen deficiency, necrosis (death) of these chlorotic (pale) areas is fairly rapid, with the tip becoming orange to dark brown and shrivelling, while the remainder turns yellow. At this stage the second leaf has taken on the early symptoms of phosphorus deficiency.
- By tillering, (uncommon) symptoms of severe deficiency are dull dark green leaves with slight mottling of the oldest leaf.

49 GRDC (2012). Crop nutrition: Phosphorus management – Western region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2012/11/grdc-fs-phosphorusmanagements

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

51 Pandey, R., Singh, B., & Nair, T. V. R. (2005). Impact of arbuscular-mycorrhizal fungi on phosphorus efficiency of wheat, rye, and triticale. *Journal of plant nutrition*, *28*(10), 1867–1876.

Photo 6: *Stunted early growth with reduced tillers in P deficient crop on the left.*

Source: DAFWA

Photo 7: *P deficient plants on the left are later maturing with fewer smaller heads.*

Source: DAFWA

Photo 8: *Dark leaves with necrosis moving down from the tip of the oldest leaf.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing nitrogen deficiency in wheat	Small less tillered and light green plants	Phosphorus deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing.
Diagnosing molybdenum deficiency in cereals	Small less tillered and light green plants	Phosphorus deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing.
Diagnosing potassium deficiency in wheat	Small less tillered and light green plants	Phosphorus deficient plants are thinner with darker leaves and older leaf tip death without leaf yellowing.

Plants have a high requirement for phosphorus during early growth. As phosphorus is relatively immobile in the soil, topdressed or sprayed fertiliser cannot supply enough to correct a deficiency.

Phosphorus does leach on very low PBI (a measure of phosphorus retention) sands, particularly on coastal plains. Topdressing is effective on these soils. [52]

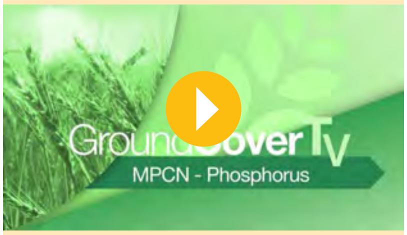
52 DAFWA. Diagnosing Phosphorus deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-wheat

MORE INFORMATION

Crop nutrition: Phosphorus management – Western region Factsheet

VIDEOS

WATCH: GCTV13: Phosphorus deficiency.



WATCH: Improving phosphate use efficiency.

Soil testing

Testing of the phosphorus levels in your soil is important and will help in the budgeting of your phosphorus dollar. Thirty to 50% of WA growers conduct regular soil testing, the highest rate in the country.

Taking random samples of the surface soil (0 to 10 cm), typically from between the rows, from different yield zones of cropping paddocks is one way to understand the P status of the soil and, consequently, to inform decisions about fertiliser expenditure and application rates. Using GPS to sample the same site every three to four years is another approach.

This allows the grower to track changes in soil test P, potassium (K) and pH over time. Soil test results will indicate if there is likely to be a response to a fertiliser nutrient. This is the start of the process for estimating the approximate amount of nutrient required to achieve a target yield. [53]

The release of phosphorus is related to:

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

Available phosphorus tests like the Colwell and Olsen's phosphorus test don't measure available phosphorus. Rather they express an indication of the rate at which phosphorus may be extracted from the soils. This indicator of rate is calibrated with field trials. There is a relationship between Total Soil Phosphorus and Colwell Phosphorus and this can enable you to predict when a given level of phosphorus input (fertiliser) or output (product removal) will result in a risk of phosphorus rate of supply becoming a limiting factor. [54]

5.6 Sulfur

Sulfur is an essential plant nutrient required for the production of amino acids which in turn make up proteins. In cereals lower sulfur levels lead to lower protein and given this affects the quality of the flour, the price received for this grain will be reduced. Lack of sulfur will also affect the oil content and hence the price received for canola. Yield losses also occur in low sulfur situations. Ideally, plants will take up sulfur at the same levels as phosphorus.

Sulfur is present in varying amounts in nearly all soils. Soils with clay and gravel have generally more sulfur present than sandier soils from high rainfall areas. The sandier soils from higher rainfall areas do not have any ability to restrict the leaching of water soluble sulfur. Sulfur remaining in plant residues is readily recycled into the soil. [55]

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 soil S test to predict plant available S. [56]

The forage production potential of triticale and wheat is essential to many livestock producers. Very few data are available concerning the effects of sulfur fertilisation on production and quality of triticale or wheat forage. Greenhouse research was conducted to evaluate the addition of S as either ammonium thiosulfate (ATS) or ammonium sulfate (AS) on production and quality of triticale and wheat forage on four different soils. Sulfur fertilisation increased forage yields and S concentrations of

53 GRDC (2012). Crop nutrition: Phosphorus management – Western region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2012/11/grdc-fs-phosphorusmanagements

54 Bailey G, Brooksby T. Phosphorus in the South East Soils.

55 Summit Fertilisers. Sulfur. http://www.summitfertz.com.au/research-and-agronomy/sulphur.html

56 GRDC (2014). Crop nutrition: Soil testing for crop nutrition – southern region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

both crops on all soils, and in many cases, resulted in higher N concentrations in the forage. Sulfur fertilisation also increased *in vitro* digestibility of wheat, but had little effect on triticale digestibility. Both S sources performed similarly. Application of S after the first clipping was effective in increasing second clipping forage production on three of the four soils, and forage S concentrations were dramatically increased for both crops on all soils. Although the magnitude of response varied, S fertilisation was effective in increasing production and quality of triticale and wheat forage grown in the greenhouse. [57]

Treatments of nitrogen and phosphorous fertilisers have been found to significantly increase the dry matter, sulfur concentrations and sulfur uptake of triticale compared to unfertilised treatments. [58]

One study found that Sulfur (20 kg ha^{-1}) applied to plots of triticale produced higher days to anthesis (126). [59]

Sulfur in WA

Historically, S has been adequate for crop growth because S is supplied in superphosphate, in rainfall in coastal areas and some from gypsum. In the Southern region sulfur-responsive soils are uncommon in cereals, but can be seen in canola. Sulfur inputs to cropping systems have declined with the use of TSP, MAP and DAP which are low in S. Sulfur is also subject to leaching and in wet seasons may move beyond the root zone.

Sandy-textured soils in Western Australia are naturally low in sulfur and applied sulfur is readily leached from the top 10 cm, especially in high rainfall areas.

The use of fertilisers containing sulfur somewhat masks the low levels of sulfur present in the soil, however the introduction of more sensitive crops such as canola and the change to compound fertilisers that are low in sulfur has increased the frequency of sulfur deficiency seen in crops. High rainfall can leach sulphate from the root zone early in the growing season, leaving young crops deficient. Other factors that can induce deficiency in crops include sub-soil constraints such as acidity, sodicity and hardpan, and the level nitrogen in the soil can limit the crop's ability to access subsoil sulphate.

The mobile nature of sulfur in the soil, and its capacity to be mineralised through the breakdown of organic matter, makes it difficult to reliably predict when a crop will respond to an application of sulfur.

A synergistic relationship exists between sulfur, nitrogen and phosphorus that affects plant uptake and efficient use of these nutrients. Too much nitrogen can induce sulfur deficiency in plants. Grain yields increase when all three nutrients are in sufficient supply and in the correct ratio.

Most sulfur present in the soil is bound in organic compounds but plants can only take up the mineral sulphate form. Cultivation releases sulfur held in organic matter. In no-till systems soil organic matter breaks down slowly, releasing mineral sulfur for crop use. Sulfur mineralisation is low in cooler months, as is root exploration, which can cause temporary deficiency in crops, seen as patches that disappear when the soil temperature increases. Mineralisation is higher in the warmer months and under moist soil conditions. Sulphate adsorption occurs in the soil layers below 10 cm, which can make a significant contribution to crop growth once crop roots have reached the subsoil.

The rate of sulphate leaching is highly variable, depending on seasonal conditions and the water holding capacity of the soil, and is closely related to the rate of nitrate leaching. These two nutrients are best considered together when planning fertiliser

57 Feyh, R. L., Lamond, R. E., Whitney, D. A., & Sears, R. G. (1993). Sulfur fertilisation of wheat and triticale for forage production 1. *Communications in Soil Science & Plant Analysis*, *24*(5–6), 443–455.

58 Lasztity, B. (1993). The variation of sulfur contents and uptakes in triticale during growth [in Hungary]. *Agrochimica (Italy).*

59 Iqbal, B., Ahmad, B., Ullah, I., Khan, A. A., Anwar, S., Ali, A., ... & Khan, S. (2016). Effect of phosphorus, sulfur and different irrigation levels on phenological traits of Triticale. *Pure and Applied Biology*, *5*(2), 303.

applications at seeding and post-seeding to compensate for the movement of these nutrients down the profile under the current seasonal conditions. [60]

Sulfur application recommendations

In most situations (depending on climate and soil type) the recommended value, above which wheat crops will not respond to applied sulfur fertiliser, are as follows:

- 6.0 using 0–10 cm and 5.3mg S/kg using 0–30 cm across all rainfall zones
- 3.5 using 0–10 cm and 3.2mg S/kg using 0–30 cm in low rainfall zones. [61]

Deficiency symptoms

Paddock

- Areas of pale plants (Photo 9).

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 10).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red.

Photo 9: *Areas of pale plants characterise Sulfur deficiency (NOTE: many nutrient deficiencies also exhibit pale patches).*

Source: DAFWA

60 GRDC. (2015). Hot Topics: Sulfur strategies for Western region. https://grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region

61 GRDC. (2015). Hot Topics: Sulfur strategies for Western region. https://grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region

Photo 10: *Leaves remain healthy despite the yellowing.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing iron deficiency in cereals	Pale new growth.	Iron deficient plants have interveinal chlorosis.
Diagnosing group B herbicide damage in cereals	Seedlings with pale new leaves	Plants generally recover from Group B herbicide damage and leaves often have interveinal chlorosis.
Waterlogging, nitrogen, molybdenum and manganese deficiency	Pale growth.	The youngest leaves of sulfur deficient plants are affected first while the middle or older leaves are affected first with waterlogging, manganese, nitrogen and molybdenum deficiency.

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

Foliar sprays generally cannot supply enough sulfur for plant needs. [62]

Modern high analysis fertilisers will usually contain enough sulfur to supply sufficient levels to cereal crops. Canola, however, will require more than can be safely or conveniently applied using a seeding fertiliser and so extra sulfur must be applied, either before seeding as gypsum, or post seeding as Amsul, (sulphate of ammonia).

If a deficiency manifests in an established crop, this can be easily corrected with an application of sulphate of ammonia.

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

Supplies of Sulfur (Elemental or Sulphate)

Plants take up sulfur in the sulphate (SO4) form. The sulphate form is water soluble and readily leachable. The elemental form of sulfur needs to be broken down into the sulphate form before becoming available to the plant. This is achieved by a bacteria which digests the sulfur and excretes sulphate. All soils contain this bacteria. It takes about a fortnight for elemental sulfur to start breaking down, so it should be used before plant deficiency can be seen. In waterlogged conditions, where sulphate sulfur will be lost by leaching or runoff, the bacteria will become dormant, so sulfur will not be lost.

Pros and Cons of the two sulfur sources.

Sulphate Sulfur:

- Immediately available to the plant
- Water soluble
- Quick acting
- Leachable
- Can be lost with one heavy rainfall event

Elemental Sulfur:

- Sustained Release
- Not lost by leaching
- More available when maximum plant growth occurs in spring
- Will build up a sulfur "bank"
- Slow to break down.
- Not suitable to correct a visual deficiency in plants. [63]

5.7 Potassium

Key points:

- Triticale can be sensitive to potassium deficiency and responses to its application.
- Soil testing combined with plant tissue testing is the most effective means of determining potassium requirements.
- Banding away from the seed, at or within 4 weeks of sowing, is the most effective way to apply potassium when the requirement is less than 15 kg/ha.

Potassium (K) is an essential plant nutrient. Potassium has many functions including the regulation of the opening and closing of stomata, the breathing holes on plant leaves that control moisture loss from the plant. Adequate potassium increases vigour and disease resistance of plants, helps to form and move starches, sugars and oils. Available potassium exists as an exchangeable cation associated with clay particles and humus. [64]

A study in Europe found that triticale is more sensitive to potassium deficiency than phosphorus deficiency. [65]

Previous research has found that the highest rate of grain yield for triticale (6.1 t/ha–1) was obtained by application of 160 and 90 kg/ha^{-1} nitrogen and potassium, respectively. Application of different levels of Nitrogen affected grain protein of triticale, however using different amounts of potassium did not affect grain protein. [66]

63 Summit Fertilisers. Sulfur. http://www.summitfertz.com.au/research-and-agronomy/sulphur.html

64 Soilquality.org. Potassium – NSW http://www.soilquality.org.au/factsheets/potassium-nsw

65 GAJ, R. (2012). The effect of different phosphorus and potassium fertilisation on plant nutrition in critical stage and yield of winter triticale. *Journal of Central European Agriculture*, *13*(4).

66 Tababtabaei, S. A., & Ranjbar, G. H. (2012). Effect of different levels of nitrogen and potassium on grain yield and protein of triticale. *International Research Journal of Applied and Basic Sciences*, *3*(2), 390–393.

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. [67]

High potassium (K): sodium (Na) ratios in wheat and some triticale varieties can induce magnesium (Mg) deficiency (tetany) in grazing stock. Surveys in southern Australia showed that all varieties of cereals tested had a K:Na ratio that could cause magnesium deficiency in livestock.

MORE INFORMATION

Mineral supplements needed when grazing cereals

One contributing factor to the variation in animal gains is the mineral nutrition provided by cereals to grazing livestock. The magnesium (Mg) content of cereal is typically satisfactory for stock, but the high potassium (K) content and very low sodium (Na) content of forage result in a high rumen K:Na ratio, which impedes magnesium absorption in the rumen.

Livestock (sheep and cattle) grazing cereals can therefore have a sodium deficiency and a magnesium deficiency (tetany). [68]

What to look for

Paddock

- Smaller lighter green plants with necrotic leaf tips, generally on sandier parts of the paddock or between header or swathe rows (Photo 11).
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease.

Plant

- Plants appear paler and weak (Photo 12).
- 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.
- Yellowing leaf tip and leaf margins sometimes generates a characteristic green 'arrow' shape towards leaf tip.

67 GRDC (2014). Crop nutrition: Soil testing for crop nutrition – southern region Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

68 Bell L, Dove H. (2012). Ground Cover Issue 98: May-June 2012. Mineral supplements needed when grazing cereals. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-98-May-June-2012/Mineral-supplements-needed-when-grazing-cereals

Photo 11: *Header rows have less symptoms.*

Source: DAFWA

Photo 12: *Potassium deficient plants may display floppy older leaves and furled flag leaf from water stress. Affected plants are paler, weak and more susceptible to leaf disease. Discoloured leaf tissue can be bright yellow.*

Source: DAFWA

What else could it be?

Condition	Similarities	Differences
Diagnosing molybdenum deficiency in cereals	Pale plants with leaf tip death.	Potassium deficient plants do not have white or rat-tail heads, and have more marked contrast between yellow and green sections of affected leaves.
Diagnosing nitrogen deficiency in wheat	Pale plants with oldest leaves most affected.	Potassium deficient plants have more marked leaf tip death and contrast between yellow and green sections of affected leaves, and tillering is less affected.
Diagnosing spring drought in wheat and barley	Water stressed plants with older leaves dying back from the tip, yellowing progressing down from tip and edges and often leaf death occurs.	The main difference is that potassium deficiency is more marked in high growth plants in good seasons.
Diagnosing root lesion nematode in cereals	Smaller, water stressed pale plants.	Root lesion nematode affected plants have 'spaghetti' roots with few feeder roots.

Top-dressing potassium will generally correct the deficiency. Foliar sprays generally cannot supply enough potassium to overcome a severe deficiency and can also scorch crops. [69]

Assessing potassium requirements

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

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

Potassium available in the soil is measured by the Colwell K or Exchangeable K soil tests. The amount of potassium needed for plant nutrition depends on soil texture (Table 9).

Table 9: *Critical (Colwell) soil test thresholds for potassium (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 potassium to be present, but are more likely to show deficiencies. Clay soils require more potassium to be present, but are more capable of supplying replacement potassium through the weathering of clay minerals.

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

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

Fertiliser types

Sulphate of potash (SOP—potassium sulphate) is usually recommended if potassium is deficient. Applying the cheaper muriate of potash (MOP—potassium chloride) also corrects potassium 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 nitrogen and potassium in a highly water soluble (and available) form, but is rarely used in broadacre farming because of its cost.

Fertiliser placement and timing

Potassium generally stays very close to where it is placed in the soil. Banded potassium has been shown to be twice as accessible to the crop as top-dressed potassium. 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 potassium drill row or seedlings may miss the higher levels of potassium. High band rates (>15 kg/ha) of potassium can inhibit sensitive crops (e.g. lupins, canola). If a paddock is severely deficient then potassium needs to be applied early in the season, at seeding or up to four weeks after. [70]

5.8 Micronutrients

Key points:

- 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.
- 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. Most soils in Western Australia (WA) are naturally deficient in the trace elements copper (Cu), zinc (Zn), manganese (Mn) and molybdenum (Mo).

Zn deficiency can severely limit annual pasture legume production and reduce cereal grain yields by up to 30%. Cu deficiency is also important because it is capable of causing total crop failure.

If 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 south-western 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.

70 Soilquality.org. Potassium. http://www.soilquality.org.au/factsheets/potassium-nsw

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. [71]

Triticale grows productively on alkaline soils where certain trace elements are deficient for other cereals. [72]

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.

In early trials it was reported that triticale commonly expressed the copper (Cu) efficiency trait derived from its cereal rye parent, and had efficiency traits for Zinc (Zn) and Manganese (Mn). Triticale usually performs remarkably well on highly calcareous soils which are often deficient in Mn and Zn and sometimes Cu. [73]

One study from Europe suggests that calcium, magnesium and potassium are the most limiting mineral nutrients to triticale yield. [74]

DAFWA recommends that managers complement soil testing (for macronutrients) with tissue testing as part of a regular fertiliser management program, to monitor the impact of fertiliser and liming programs. This will help identify approaching trace element deficiencies before production losses occur.

By using test results, managers can identify which trace elements are needed, and avoid adding expensive trace element fertilisers when they are unnecessary.

Adding high levels of nitrogen fertilisers also increases acidification, and this then needs lime to bring the pH back into the desired range. Over-use of Lime can change the pH enough that Cu, Mn and Zn become less available to plants. [75]

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.

5.8.1 Manganese

Many triticale cultivars carry tolerance to soils high in manganese, which is typical in some soils of Australia. [76]

Deficiency symptoms

Paddock

- Manganese deficiency often appears as patches of pale, floppy plants in an otherwise green healthy crop (Photo 13).

Plant

- Frequently plants are stunted and occur in distinct patches.
- Initially, middle leaves are affected first, but it can be difficult to determine which leaves are most affected as symptoms rapidly spread to other leaves and the growing point (Photo 14).
- Leaves develop interveinal chlorosis and/ or white necrotic flecks and blotches.
- Leaves often kink, collapse and eventually die.

71 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/detecting-and-managing-trace-element-deficiencies-in-crops

72 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

73 Reuter D. (2007). Trace element disorders in South Australian Agriculture. http://www.pir.sa.gov.au/__data/assets/pdf_file/0011/49619/Trace_Element_disorders_in_SA.pdf

74 GAJ, R. (2012). The effect of different phosphorus and potassium fertilisation on plant nutrition in critical stage and yield of winter triticale. *Journal of Central European Agriculture*, *13*(4).

75 DAFWA. (2016). Trace elements for high rainfall pastures. https://www.agric.wa.gov.au/soil-acidity/trace-elements-high-rainfall-pastures

76 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

- Tillering is reduced, with extensive leaf and tiller death. With extended deficiency, the plant may die.
- Surviving plants produce fewer and smaller heads.

Photo 13: *Patches of pale floppy plants in otherwise healthy crop.*

Source: DAFWA

Photo 14: *Middle leaves are affected first, showing yellowing and necrosis.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing zinc deficiency in wheat	Pale plants with interveinal chlorosis and kinked leaves	Differences include linear 'tramline' necrosis on zinc deficient plants. Manganese deficient plants are more yellow and wilted
Diagnosing nitrogen deficiency in wheat	Pale plants	Nitrogen deficient plants do not show wilting, interveinal chlorosis, leaf kinking and death
Diagnosing waterlogging in cereals	Pale plants	Waterlogged plants do not show wilting, interveinal chlorosis, leaf kinking and death
Diagnosing iron deficiency in cereals	Pale plants	New leaves are affected first and plants do not die
Diagnosing sulfur deficiency in cereals	Pale plants	New leaves are affected first and plants do not die

Managing Manganese deficiency

- Foliar spray.
- Acidifying ammonium nitrogen fertilisers can reduce manganese deficiency by lowering pH and making manganese more available to growing crops.
- Manganese fertiliser is effective but expensive as high rates and several applications are required to generate residual value.

- Seed manganese coating treatments have little effect in correcting the deficiency. [77]

Due to the detrimental effect of high soil pH on Mn availability, correction of severe Mn deficiency on highly calcareous soils can require the use of Mn-enriched fertilisers banded with the seed (three to five kg Mn/ha) as well as one to two follow up foliar sprays (1.1 kg Mn/ha). In the current economic climate growers on Mn-deficient country have tended not to use Mn-enriched fertilisers (due to their cost) but have relied solely on a foliar spray. This is probably not the best or most reliable strategy for long term management of the problem.

Neither soil nor foliar Mn applications have any residual benefits and must be re-applied every year. Another approach is the coating of seed with Mn. This technique is cheap and will probably be the most effective in conjunction with foliar sprays and/or Mn enriched fertilisers. Mn deficiency in lupins must be treated with a foliar spray at mid-flowering on the primary laterals. The use of acid fertilisers (e.g. nitrogen in the ammonium form) may also partially correct Mn deficiency on highly alkaline soils but will not overcome a severe deficiency.

Mn deficiency in crops can also be corrected by fluid application at seeding. [78]

5.8.2 Copper

Triticale is tolerant to low concentrations of available copper in soil, a condition widely associated with poor sandy soils in Australia. Such soils may contain enough total copper for tens of thousands of crops but it is relatively unavailable to widely grown cultivars of wheat, oats and barley. [79]

IN FOCUS

Tolerance of triticale, wheat and rye to copper deficiency and low and high soil pH

The tolerance of triticale to low copper status in a soil adjusted to extremes of pH was determined in pots in a glasshouse experiment, and compared with the tolerance of its parent species, wheat and rye. Wheat plants were extremely sensitive to copper deficiency at all soil pH values and failed to produce heads or grain, whereas rye produced maximum yield irrespective of copper status or soil pH. Intermediate tolerance of triticale was demonstrated by virtue of the copper-pH-genotype interaction in that triticale was tolerant like rye at pH 5.0, but sensitive at pH 8.4 like wheat.

Concentrations of copper were highest in rye and lowest in wheat, and decreased with increasing pH. The uptake of copper into grain and shoot was also lowest in wheat, and showed the same pH dependence as concentration. The appearance of copper deficiency symptoms on all plants which had low yields suggests that the major effect of pH in this system was on copper availability; the change in availability was, however, insufficient to affect the response of wheat (highly sensitive) or of rye which is highly tolerant. Triticale responded dramatically to the pH treatment and as predicted for such a hybrid was generally intermediate in tolerance to copper deficiency. [80]

77 DAFWA. Diagnosing manganese deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-wheat

78 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/detecting-and-managing-trace-element-deficiencies-in-crops

79 Graham, R. D. (1978). Tolerance of triticale, wheat and rye to copper deficiency.

80 Harry, S. P., & Graham, R. D. (1981). Tolerance of triticale, wheat and rye to copper deficiency and low and high soil pH. *Journal of Plant Nutrition*, *3*(1–4), 721–730.

Deficiency symptoms

Paddock

- Before head emergence deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green healthy crop (Photo 15).
- 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 copper deficiency before flowering is growing point death and tip withering, and/or bleaching and twisting up to half the length of young leaves (Photo 16).
- 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.
- Grain in less severely affected plants may be shrivelled. Heads with full grain droop due to weak stems.

Photo 15: *Pale necrotic flag leaf at head emergence.*

Source: DAFWA

Photo 16: *Partly sterile head and twisted flag leaf.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing false black chaff in wheat	Discouration on the upper stem and glumes	False black chaff does not affect yield or grain quality
Diagnosing molybdenum deficiency in cereals	White heads and shrivelled grain	Molydenum deficiency affects middle leaves first rather than the youngest leaf
Diagnosing boron deficiency in wheat	Youngest leaf death	Boron deficient plants are dark rather than light green and affected leaves have marginal notches and split near the base
Diagnosing stem and head frost damage in cereals	White heads, shrivelled grain, late tillers and delayed maturity	Spring frost does not cause death or twisting of the flag leaf and is location specific (frost-prone areas)
Diagnosing take-all in cereals	White heads and shrivelled grain	Take-all causes blackened roots and crowns and often kills the plant

Managing copper deficiency

- Foliar spray (only effective in the current season) or drilled soil fertiliser.
- Copper foliar sprays are not effective after flowering as sufficient copper is required pre-flowering for pollen development.

- Mixing copper throughout the topsoil improves availability due to more uniform nutrient distribution.
- As copper 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 copper 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. [81]

Traditionally, Cu deficiency has been corrected by applying Cu-enriched fertilisers and incorporating them into the soil. Most soils require 2 kg/ha of Cu to fully correct a deficiency, and this application may be effective for many years.

Due to the excellent residual benefits of soil-applied Cu, Cu deficiency in crops and pastures has been largely overcome in most areas from the use of the 'blue stone' mixes in the 1950s and 1960s.

However, Cu deficiency may be re-surfacing as a problem due to a number of reasons:

- The applications of Cu made 20–40 years ago may be running out
- The use of nitrogen fertilisers is increasing and they will increase the severity of Cu deficiency
- Cu deficiency is affected by seasonal conditions and farming practices (e.g. lupins in a lupin/wheat rotation make Cu deficiency worse in succeeding wheat crops).

Application of Cu by Cu-enriched fertilisers will currently cost approximately $19.00/ha. Cu deficiency in crops can also be corrected by fluid application at seeding with an application cost as low as $4.60/ha. Performance of soil applied Cu will improve with increased soil disturbance.

Although Cu deficiency is best corrected with soil applications, foliar sprays will also overcome the problem in the short term. A foliar spray of Cu (75–100 g/ha of Cu) is very cheap (approximately 90c/ha for the ingredient) but a second spray immediately prior to pollen formation may be necessary in severe situations. This was the case in a trial conducted on lower Eyre Peninsula in 2015, where a late foliar spray was necessary to completely eliminate Cu deficiency in an area that was extremely deficient for Cu and where the problem was exacerbated by a dry spring when wheat was forming pollen and setting grains. [82]

Although plants do have a requirement for copper, the main reason copper is applied is for the benefit of grazing stock. Copper deficiency is more common on light textured soils such as sands or sandy loams. Where required, copper is normally applied with the fertiliser at 1–2 kg/ha every 3–6 years. Inclusion of copper in the fertiliser will provide a long term supply to pasture and grazing stock. Where copper deficiency has been diagnosed in stock, more direct supplementation such as copper drenches are recommended. [83]

5.8.3 Zinc

Deficiencies of zinc are well known in all cereals and cereal-growing countries. Physiological evidence suggests that a critical level for zinc is required in the soil before roots will either grow into it or function effectively; it is likely the requirement is frequently not met in deep sandy, infertile profiles widespread in southern Australia.

81 DAFWA. Diagnosing copper deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-wheat

82 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/detecting-and-managing-trace-element-deficiencies-in-crops

83 Agriculture Victoria. (2008). Trace elements for dryland pastures.https://trove.nla.gov.au/work/32193714?q&versionId=39111757

Triticale is thought to have a high tolerance to Zinc (Zn) deficiency compared to wheat. The resistance index for Zn in triticale has been estimated at 75 per cent, second only to rye, which is a very resistant crop to Zn deficiency. [84]

In one experiment, Zn deficiency symptoms were either absent or only slight in triticale and rye, and occurred more rapidly and severely in wheats, particularly in durum wheats. In field experiments at the milk stage, decreases in shoot dry matter production due to Zn deficiency were absent in rye, and were on average 5 per cent in triticale, 34 per cent in bread wheats and 70 per cent, in durum wheats. Zinc fertilisation had no effect on grain yield in rye but enhanced grain yield of the other cereals. Zinc efficiency of cereals, expressed as the ratio of yield (shoot dry matter or grain) produced under Zn deficiency compared to Zn fertilisation were, on average, 99 per cent for rye, 74 per cent for triticale, 59 per cent for bread wheats and 25 per cent for durum wheats. [85]

Deficiency symptoms

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 17).
- Maturity is delayed. [86]

84 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

85 Cakmak, I., Ekiz, H., Yilmaz, A., Torun, B., Köleli, N., Gültekin, I., ... & Eker, S. (1997). Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. *Plant and Soil*, *188*(1), 1–10.

86 DAFWA. Diagnosing Zinc Deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

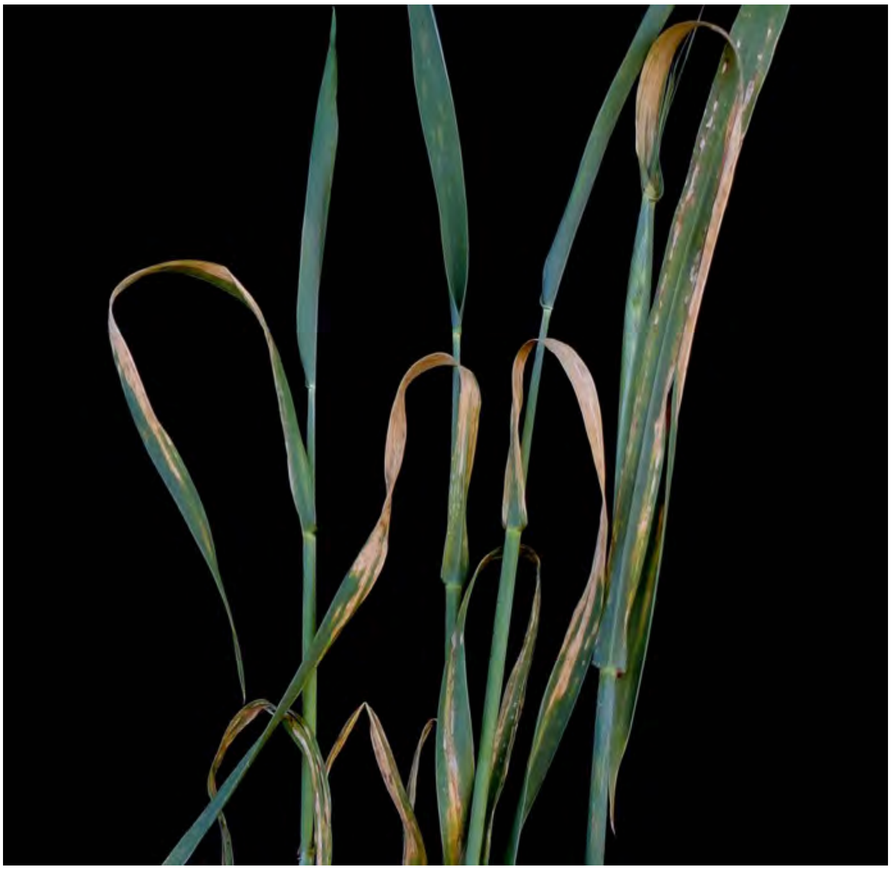


Photo 17: *Leaves yellow and die and can have tramline effect on leaves. Necrosis halfway along middle and older leaves causes them to droop.*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing manganese deficiency in wheat	Leaf kinking, pale lesions, streaks and wilted plants	Manganese deficient plants are very pale, are more common as patches of limp dying plants and lack the parallel necrotic tramlines adjoining the midrib
Diagnosing wheat streak mosaic virus	Stunted plants with many tillers and striped leaf lesions	Zinc deficient plants have pale linear spots or lesions that can develop into parallel 'tramlines' and lack vivid yellow streaks towards the leaf tip
Diagnosing yellow dwarf virus	Stunted plants with many tillers and striped leaf lesions	Zinc deficient plants have pale linear spots or lesions that can develop into parallel 'tramlines' and lack vivid yellow streaks towards the leaf tip

Managing Zinc deficiency

- 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 zinc is immobile in the soil topdressing is ineffective, only being available to the plant when the topsoil is wet.
- Mixing zinc throughout the topsoil improves availability due to more uniform nutrient distribution.

- Zinc drilled deep increases the chances of roots being able to obtain enough zinc 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. [87]

Zinc may be required on light textured soils such as sands or sandy loams and particularly those that are alkaline. The more alkaline the soil, the lower the availability of zinc for plant uptake. Zinc responses on pasture are rare, but where required zinc should be applied at about 1–2 kg/ha, every 5–6 years. [88]

Correction of Zn deficiency in a way which provides benefits after the year of treatment is possible through the use of Zn-enriched fertilisers or a pre-sowing spray of Zn onto the soil (incorporated with subsequent cultivations). There is also the option of a Zn-coated urea product which can be used to supply Zn to the crop, and is most useful when pre-drilling urea before the crop.

Another option that will also provide long term benefits but has become available only recently is the application of fluid zinc at seeding. The advantage of this approach is that it will provide residual benefits for subsequent crops and pastures and has a low up-front application cost (providing you ignore the capital investment in a fluid delivery system!). At current prices, a typical application may cost about $6.00/ha (this is 1 kg of Zn/ha).

Only Zn-enriched fertilisers of the homogenous type (fertiliser manufactured so that all granules contain some Zn) are effective at correcting Zn deficiency in the first year of application. A rate of two kilograms of elemental Zn per hectare applied to the soil is necessary to overcome a severe Zn deficiency and should persist for three to ten years (depending on soil type). Short intervals between repeat applications of Zn will be necessary on heavy and calcareous soils in the high rainfall areas, while seven to ten year intervals will be acceptable in the low rainfall areas. Following an initial soil application of 2 kg Zn /ha repeat applications of 1 kg/ha will probably be sufficient to avoid the reappearance of Zn deficiency in crops and pastures. Most zinc-enriched fertilisers are now not sold as pure homogeneous types, but providing a homogeneous fertiliser is used as part of the mix then the final product is still satisfactory for correcting Zn deficiency. For example, the company may produce a diammonium phosphate (DAP) Zn five per cent 'parent' product which has Zn on every granule which they will then blend with straight DAP to give 1 and 2.5 per cent products for the retail market. This option will currently cost approximately $17.00/ha.

Zn deficiency can be corrected in the year that it is recognised with a foliar spray of 250–350 g Zn/ha but it has no residual benefits and is therefore not the best approach for a long-term solution. This option will currently cost approximately $1.00/ha (plus the cost of the operation). Zinc can be mixed with many herbicides and pesticides but not all, so check with your supplier for compatible tank mixes before you make the brew. Recent trials in eastern Australia suggest that chelated sources of trace elements are no more effective at correcting a deficiency than their sulphate cousin, although older results from WA showed that there are situations where they can be superior.

Seed dressings of zinc are another option for managing Zn deficiency. These products are effective and will supply Zn to the young crop but they will not completely overcome a severe deficiency. Nor will they increase soil reserves of Zn. Seed with high internal levels of Zn can also be used in a similar way. However, both approaches should be used in conjunction with soil applications to correct and manage Zn deficiency in the long term. This option will currently cost approximately $3.00/ha. [89]

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87 DAFWA. Diagnosing Zinc Deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

88 Agriculture Victoria. (2008). Trace elements for dryland pastures. https://trove.nla.gov.au/work/32193714?q&versionId=39111757

89 Wilhelm N, Davey S. (2016). GRDC Update Papers: Detecting and managing trace element deficiencies in crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/detecting-and-managing-trace-element-deficiencies-in-crops

5.8.4 Iron

Iron is involved in the production of chlorophyll and is a component of many enzymes associated with energy transfer, nitrogen reduction and fixation and lignin formation. Iron deficiencies are mainly manifested by yellow leaves due to low levels of chlorophyll. Leaf yellowing first appears on the younger upper leaves in interveinal tissues. Severe iron deficiencies cause the leaves to turn completely yellow or almost white, and then brown as leaves die. Iron deficiencies are found mainly in alkaline soils, although some acidic, sandy soils, low in organic matter, may also be iron deficient. Cool, wet weather enhances iron deficiencies especially in soils with marginal levels of available iron. Poorly aerated or compacted soils also reduce iron uptake. High levels of available phosphorus, manganese and zinc in soils can also reduce iron uptake. [90]

Symptoms

Paddock

- Pale plants particularly in waterlogged or limed areas (Photo 18).

Plant

- Youngest growth is affected first and most severely.
- Symptoms begin with young leaves turning pale green or yellow.
- Inter-veinal areas become yellow and in severely deficient plants the inter-veinal area turns almost white (Photo 19).
- New growth remains yellow for some time before leaves start to die.
- Old leaves remain pale green and apparently healthy.
- Severely affected plants are stunted with thin spindly stems.

Photo 18: *Pale green to yellow plants.*

Source: DAFWA

90 Schlegel, R. H. (2013). *Rye: genetics, breeding, and cultivation*. Crc Press.

Photo 19: *Pale yellow, iron deficient leaves, most showing prominent green veins (right) compared with dark green healthy leaf (left).*

Source: DAFWA

What else could it be

Condition	Similarities	Differences
Diagnosing sulfur deficiency in cereals	Pale plants with pale new growth	Sulfur deficient plants do not have interveinal chlorosis
Diagnosing group B herbicide damage in cereals	Pale seedlings with interveinal chlorosis on new leaves	Herbicide damaged plants generally recover and are not restricted to waterlogged areas
Waterlogging, nitrogen, molybdenum and manganese deficiency	Pale growth	However middle or older leaves are affected first

Managing iron deficiency

- No yield responses to iron to justify soil application.
- Where symptoms occur, particularly in cold and wet conditions, they are frequently eliminated by increased soil and air temperatures.
- Foliar sprays will remove the symptoms where they occur in highly calcareous or limed soils. [91]

5.9 Nutritional deficiencies

Many soils in the cropping zone of south-western Australia are deficient in macro and micronutrients in their native condition. To help identify nutritional deficiencies, see the GRDC Winter Cereal Nutrition: the Ute Guide.

MORE INFORMATION

Crop nutrition Factsheet

Detecting and managing trace element deficiencies in crops

91 DAFWA. Diagnosing iron deficiency in wheat. https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-cereals

Weed control

Key messages:

- Weed control in triticale is similar to that for wheat.
- There are mixed reviews on triticale's ability to compete with weeds. Triticale is a more vigorous crop than wheat so offers greater competition against weeds, [1] however, it grows a bit more slowly than spring wheat, so annual grasses and other weeds can be problematic. [2]
- Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as cereal rye. [3]
- Triticale is a relatively new crop and consequently may not have many, if any, herbicides recommended for it.
- Integrated weed management practices for becoming more common in Australian cropping systems with promising results.
- Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition.

MORE INFORMATION

Impact of weeds on Australian grain production

Australia's most comprehensive analysis of the cost of weeds in cropping systems has shown that the overall annual cost to Western Australian grain growers is $927 million or $117 per hectare. [4] Annual ryegrass (*Lolium rigidum*) is one of the most serious and costly weeds of annual winter cropping systems in south-western Australia (Photo 1). [5]

Photo 1: *Annual ryegrass is on the most problematic weeds in Australia (left). Here it is heavily infesting a cereal paddock (right).*

Source: FarmPress

Triticale is a relatively new crop in many parts of the world and as a consequence may not have many, if any, herbicides or pesticides recommended for it. Check on-label recommendations at www.apvma.gov.au. However, some studies indicate that triticale may be less tolerant to some herbicide cocktails than wheat. Newer herbicides as well as pesticides are now being released with recommendations for use on triticale in many parts of the world. [6]

1 Clarke S, Roques S, Weightman R, Kindred D. (2016). Understanding Triticale. https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf

2 Northern Grain Growers (US). Triticale. http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

3 Albert lea Seed. (2010). Triticale. http://www.alseed.com/UserFiles/Documents/Product%20Info%20Sheets-PDF/Basics%20Triticale-2010.pdf

4 Lee N. (2016). Comprehensive study reveals cost of weeds to WA growers. https://grdc.com.au/Media-Centre/Media-News/West/2016/04/Comprehensive-study-reveals-cost-of-weeds-to-WA-growers

5 Peltzer S. (2016). Annual ryegrass. DAFWA. https://www.agric.wa.gov.au/grains-research-development/annual-ryegrass

6 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

Weed competitiveness of triticale

Good soil fertility along with vigorous germination and fast emergence may be one of the most efficient ways to reduce weeds through competition. A vigorously growing crop is usually weed-free.

The actual competitiveness of different cereals depends on growing conditions, management practices, weed load and relative growth stage of the weed and crop. Triticale's competition to weeds is provided by its leafiness and height, which impact light and moisture competition. Even so, there is still a wide range of weeds that can be a problem for triticale.

Triticale may have some allelopathic effect which can inhibit the germination and growth of weeds but this effect is not as high as its parent crop, cereal rye. [7]

Based on research from Southern NSW the most competitive crops in the face of annual ryegrass at 300plants/m^{-2} are oats > cereal rye > triticale > oilseed rape > barley > wheat> field pea > lupin. [8]

Suppression of the grass weed annual ryegrass, *Lolium rigidum* by wheat, triticale and rye was compared in field trials at Wagga Wagga in 1993. Triticale and Cereal rye appeared to be more competitive than wheat, with a biomass of annual ryegrass at maturity of 70 g/m^2 with triticale compared to 170 g/m^2 with wheat. Triticale has large seeds which lead to rapid early growth and the capacity to suppress weeds via good competitive ability. Early seedling vigour, superior height and broad leaves appeared to influence the greater competitive ability of the triticale and cereal rye. [9]

One study found that grazing systems involving triticale had an equal effect on weed control for some common weed species as the use of a herbicide. [10]

A general rule of thumb in cereals is that taller, leafier varieties are more competitive due to the ability to close the canopy quickly. Being somewhat weed competitive, triticale is sometimes used in a 'green' approach in crop rotations to reduce weed seed banks. When seeded early and under good conditions, triticale will compete with many weed species. Although it is not as effective as rye, triticale can be very competitive with wild oats.

Triticale's potential as a herbicide substitute is of particular interest to organic growers, who could use this crop for partial control of weeds in their rotations. While triticale's 'competitiveness' is known, there is not a large database about its effectiveness for weed control when used in this manner. [11]

However, because triticale grows more slowly than spring wheat, annual grasses and other weeds can be problematic. To minimise weeds, prepare the seedbed so it is as clean as possible before planting, and be sure to practice crop rotation. Planting early will help with the quick establishment of a triticale stand and may stave off early weed pressure. Triticale can also be inter-seeded with another crop (including forage grasses or legumes) to aid in weed competition and nutrient management. [12]

Best management practices for weed control

Best management practices for weed control in triticale are similar to those for wheat. These include:

- Seed at higher rates and ensure proper fertility, which can help control weeds in triticale.

7 Albert lea Seed. (2010). Triticale. http://www.alseed.com/UserFiles/Documents/Product%20Info%20Sheets-PDF/Basics%20Triticale-2010.pdf

8 Lemerle, D., Verbeek, B., & Coombes, N. (1995). Losses in grain yield of winter crops from Lolium rigidum competition depend on crop species, cultivar and season. *Weed Research*, *35*(6), 503–509.

9 Lemerle, D., & Cooper, K. (1996). Comparative weed suppression by triticale, cereal rye and wheat. In *Triticale: Today and Tomorrow* (pp. 749–750). Springer Netherlands.

10 Schoofs and Entz (2000) in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

11 Alberta Agriculture and Forestry. (2016). Triticale Crop Protection. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10572

12 Northern Grain Growers (US). Triticale. http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

- Plan ahead. Chemical weed control options in triticale are limited. Select relatively clean fields to seed triticale.
- In the case of perennial weed problems, apply pre-harvest glyphosate or use as a pre-seed burn-off in direct seeded situations. Use in-crop herbicides to control or suppress broadleaf weeds.
- Use certified seed as this ensures that only triticale, and not weeds, is seeded. Certified seed is also more vigorous than bin-run seed.
- Seed early, as earlier sown triticale usually results in more competitive stand establishment, and provides a jump-start on the weeds.
- Seed shallow at between 0.5 to 1.5 inches (optimum 1.0 inch). Shallow seeding generally results in uniform seedling emergence that quickly covers the ground and competes with emerging weeds.
- Use good sanitary practices. Clean machinery and seeding equipment before seeding. [13]

6.1 Integrated weed management (IWM)

Adoption of Integrated Weed Management (IWM) tactics is crucial to sustaining long term profitable cropping rotations in Western Australia (WA). IWM achieves good weed control, helps manage herbicide resistance and drives down weed seed bank numbers.

An integrated weed management plan should be developed for each paddock or management zone based on five steps.

1. Review past actions. The history of herbicide use can be used to prioritise weed management tactics to avoid the use of high risk herbicide mode-of-action groups and identify those paddocks at risk (where weed populations can be prioritised for resistance testing)
2. Assess the current weed status (see also Herbicide resistance and Assessing weed population density)
3. Identify weed management opportunities within the cropping system. Ensure that the proposed changes to the weed management system are suited to the land, infrastructure, resources and the tactics are environmentally and economically sound.
4. Match opportunities and weeds with suitable and effective tactics.
5. Combine ideas using a rotational planner. A rotational planner needs to be drafted for each paddock and include details such as key weeds, soil type, soil pH, resistance issues, crop and pasture rotations, selected weed management tactics and plans for herbicide use.

In a well-integrated weed management plan, each target weed will be attacked using different tactics. Each tactic provides a key opportunity for weed control and is dependent on the management objectives and the target weed's stage of growth. Tactic should be combined in the same way herbicides from different herbicide mode-of-action (MOA) groups are rotated. Integrating tactics and MOA groups will reduce weed numbers, stop replenishment of the seedbank and minimise the risk of developing herbicide resistant weeds.

IWM tactics

- Reduce weed seed numbers in the soil
- Controlling small weeds
- Stop weed seed set
- Reduce weed seed numbers in the soil
- Hygiene - prevent weed seed introduction
- Agronomic practices and crop competition

13 Alberta Agriculture and Forestry. (2016). Triticale Crop Protection. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10572

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. [14]

6.1.1 IWM for triticale

Triticale has been shown to be more competitive against annual ryegrass than wheat, however a sound weed control program must be implemented to avoid a blow-out in weed seed numbers and to optimise yield.

It is vital to control weeds early in the crop's growth. Once the crop grows it then becomes more competitive.

When sowing dual purpose varieties early, choose a paddock with low weed numbers and control weeds prior to the first grazing. Strategic grazing can be used to help manage weeds. Always check grazing withholding periods before you apply post-emergent herbicides when planning to graze the crop. [15]

IN FOCUS

The effect of cultivation and row spacing on the competitive ability of triticale against weeds

Research in 2007 explored the effect of cultivation and row spacing on the competitive ability of triticale against weeds. The aim of this work was to identify agronomic management practices that enabled triticale to express its full genetic potential for competitive growth against the vigorous weedy competitor *Lolium rigidum*. This project assessed the effects of cultivation (disc ploughing), or lack thereof (zero tillage) prior to sowing, and row spacing (15, 30, 45 cm) on the competitive ability of triticale against annual ryegrass.

Historically, most of the experiments evaluating the effect of row spacing and level of cultivation in cereals have been performed on wheat hence there is little data specifically for triticale. By identifying the optimal row spacing and level of cultivation that enhance the competitive ability of triticale, it is expected that the findings will contribute to securing sustainable cereal yields by increasing the inclusion of triticale in cropping rotations, and thereby: (1) reducing the cost of weed control, (2) reducing weed induced crop yield loss, and (3) increasing uptake and utilisation of fertiliser inputs by the crop at the expense of weeds.

Unfortunately, growing conditions were less than ideal. Episodic heavy rainfall events early in the growing season caused waterlogging and poor establishment of triticale and late in the season, some degree of lodging. In addition to above average rainfall, temperatures were below average. This combination appeared to assist the growth of annual ryegrass present at high densities at the expense of triticale, the data for which was highly variable.

Under these conditions, there was no significant row spacing effect on triticale biomass, grain yield or 1000 grain weight. Cultivation, however, while not showing an early impact, increased triticale biomass and

14 Peltzer S. (2016). Developing an integrated weed management plan. DAFWA. https://www.agric.wa.gov.au/grains-research-development/developing-integrated-weed-management-iwm-plan

15 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

grain yield at harvest. In this trial, wet conditions appeared to affect the expression of competitive growth habits in both the crop and weed species present. The competitive ability was expressed more in the weed population than the crop.

A number of key experimental findings in this study validated the agro-ecological principles on which integrated weed management is based such as: (1) weeds that emerge prior or simultaneous to the crop impose the greatest weed-crop interference, particularly in those weed species that share similar morphology and phenology to cereal crops e.g. *L. rigidum*; (2) strong selection pressure from a given agronomic management practice will cause a shift in weed flora composition and may contribute to the development of single species becoming problem weeds e.g. *Fallopia convolvulus* under high crop densities; (3) early suppression of weeds, in terms of preventing germination or limiting biomass accumulation, is the most important aspect of crop competitive ability as even the most tolerant crops will have yield reductions if early weed-crop competition results in reduced crop tillering during early crop growth; and (4) the expression of competitive growth traits in cereal crops with strong genetic potential for competitive ability (e.g. triticale) is highly influenced by optimal plant densities which impose positive intra-specific competition. [16]

6.1.2 IWM trials in WA

In the northern wheatbelt of WA, focus paddock trials funded by GRDC and carried out in conjunction with the Department of Agriculture and Food WA (DAFWA) demonstrated that it is possible to profitably crop at high intensity, while eroding the weed seed bank and in-crop weed numbers.

This is despite originally having high levels of herbicide resistance. For 31 focus paddocks where IWM was used from 2001 to 2013, annual ryegrass (*Lolium rigidum*) seed bank populations fell 96% from an average 183 ryegrass plants/m^2 to only eight ryegrass plants/m^2.

At the same time, an average cropping intensity of 89% was maintained. The focus paddock project highlighted the importance of harvest weed seed control (HWSC) in reducing weed populations as part of an IWM plan. It found growers who had the most success at managing annual ryegrass were those who practiced HWSC by towing a chaff cart and/or using narrow window burning. In the eighth year of using this practice, these growers had no annual ryegrass in their focus paddocks and have averaged fewer than 1.5 ryegrass plants/m^2 ever since.

Crop competition and orientation

Crop competition and orientation are emerging as key non-herbicide weed control measures in WA.

These can include narrow row spacing, higher seeding rates, twin row seeding points, orientating crops to shade weeds in the inter-row, use of varieties that tiller well, high density pastures as a rotation option, brown manuring and inclusion of herbicide tolerant canola hybrids in crop rotations.

Research by the Department of Agriculture and Food WA (DAFWA) has shown that as crop density increases, crop biomass increases and weed growth and weed seed set fall due to crops out-shading and out-competing weeds for water and nutrients.

16 Sindel B. (2008). GRDC Final Report: UHS127 – The effect of cultivation and row spacing on the competitive ability of triticale against weeds. http://finalreports.grdc.com.au/UHS127

The challenge is to achieve this in a practical and cost effective way. Research has shown lifting seeding rates by 30–40 kg/ha, at a cost of about $15/ha, to establish 200 wheat plants/m^2can halve weed seed set in a paddock.

A 2012 trial in Mingenew demonstrated a 65% reduction in annual ryegrass *(Lolium rigidum)* seed set without the use of in-crop herbicides as a result of high crop density – using seeding rates of 160 kg/ha.

At this trial, the efficacy of Sakura® (with the active pyroxasulfone) at label rates also increased from a 95 to a 99% reduction in annual ryegrass seed set when seeding rates and crop density increased.

At a Binnu trial in 2012, increasing crop density resulted in a significant reduction in wild radish (*Raphanus raphanistrum L.*) numbers with no in-crop herbicide used (Photo 2).

Photo 2: *Wild radish growing between cereal crop rows in a trial plot in WA's northern agricultural region investigating herbicide sequences to control wild radish.*

Source: GRDC

Using narrow or paired row seeding systems (where a single seeding boot creates paired crop rows - usually 75 to 100 mm apart) can also boost crop competition.

Existing machinery can be modified for paired row seeding so that the tyne spacing best for stubble handling and sowing speed can stay the same.

GRDC-funded trials run by DAFWA in the northern agricultural region in 2013 found there was potential for paired row seeding systems - using a Stiletto seeding boot mounted to a single tyne - to improve crop competition with weeds.

MORE INFORMATION

Narrow row spacing – more crop, fewer weeds.

Paired row sowing was able to increase crop germination, establishment and density and reduce crop row spacing to rows 75 mm apart, without adding extra tynes.

Narrow row spacing plots (at 15 cm) out-yielded wider row spacing plots (at 22 cm and 30 cm) by an average 240 kg/ha.

This is the equivalent of 16 kg/cm/ha of row spacing and is consistent with findings from a recent GRDC-funded review of 50 years of national row spacing trial data.

Variety selection also has a role in crop competition and it is recommended wheat varieties with high early vigour are used to out-compete weeds.

Using good crop agronomy during the growing season and soil health best practices (particularly liming to address soil acidity) are also factors to help boost crop competition.

Crop and herbicide rotation

Rotating crop types and herbicides with different modes of action (MOA) can help to reduce the risk of herbicide resistance evolution.
Changing between broadleaf crops and cereals allows different weed control tactics to be incorporated into an IWM strategy, such as rotating herbicide MOA or crop topping etc.

A fallow period between two crops, or a crop and pasture phase, can also be an ideal time to focus on weed control in that paddock.

It is vital to rotate herbicide and physical weed control measures during this phase.

Multiple and well-timed mowing or crop topping, silage or hay production with a follow-up non-selective herbicide or heavy grazing/spray grazing are good in-crop weed control measures.

Weed detection technology

A predominantly glyphosate fallow over summer to remove weeds and conserve moisture for the next crop is common practice in the northern agricultural region of WA.

To reduce the risk of glyphosate resistance evolving in fallow weeds, some growers are using weed-detecting technology to target and spray individual weeds that survive the glyphosate application with an alternative knockdown herbicide (Photo 3).

Photo 3: *Small sensors on a boom spray will detect broad leave weeds and a single spray will operatePrecision spraying results in significant savings in herbicides.*

Photo: Evan Collis, Source: GRDC

This technology is well suited to detecting and killing patches of weeds across large-scale properties, using optical sensors to turn on spray nozzles only when green weeds are detected. This reduces total herbicide use and cost per hectare (after taking into account the initial outlay cost for machinery).

This new technology also has potential to map troublesome weed patches so these areas can be targeted with a pre-emergent herbicide before sowing.

Sales of the two weed detecting systems available in Australia - WeedSeeker® and WEEDit® - continue to increase.

A minor use permit has been issued for all Australian states for herbicide use with Weedseeker and is valid to February 28, 2019 (it will be reviewed annually).

The permit (PER11163) allows growers to use about 30 different selective grass herbicides from seven MOA groups and higher rates of paraquat and diquat.

Harvest weed seed control (HWSC)

A major biological weakness of most WA cropping weeds is that their seed does not shatter before harvest, providing a good opportunity for removal at this time.

Common HWSC tactics used in WA include:

- collecting chaff in chaff carts
- burning or grazing chaff residue
- depositing chaff on narrow windrows for burning the next autumn
- using the Harrington Seed Destructor (HSD) system to pulverise and destroy chaff and weed seed fraction as it leaves the harvester
- diverting weed seeds onto permanent tramlines
- towing a baler behind the header to remove all harvest residue.

A major benefit of these systems, aside from lowering the seed bank over a few years, is removal of both resistant and susceptible weed seeds that have survived earlier herbicide applications.

This reduces the risk of herbicide resistance evolution and reduces selection pressure on herbicides.
Australian Herbicide Resistance Initiative (AHRI) research at 25 sites across southern Australia during the 2010 and 2011 harvest found that windrow burning, chaff cart and HSD systems were equally effective at removing annual ryegrass seed from cropping paddocks.

Each of the HWSC methods led to a 55% reduction in annual ryegrass germination the following year.
AHRI research has also shown that the HSD consistently destroys 95% of annual ryegrass, wild radish, wild oats and brome grass seed present in the chaff fraction.

All HWSC systems are limited by how many weed seeds enter the front of the harvester and, therefore, typically remove about 70–80% of annual ryegrass and wild radish seed from the crop.

See Section 12: Harvest, 12.7 Harvest weed seed management for more information.

Decision support - Ryegrass Integrated Management (RIM)

IWM involves complex interactions, multiple year timeframes, many possible interventions, major environmental influences and high levels of uncertainty.

The use of computer-based models can be a valuable tool to aid decision making. Developed by AHRI, with GRDC funding, the Ryegrass Integrated Management (RIM) model evaluates the long term profitability of ryegrass control methods and reducing the weed seed bank.

RIM enables users to assess the effectiveness and budget implications of 10-year cropping and weed management scenarios using up-to-date economic parameters.

MORE INFORMATION

The latest version of RIM has a user guide and video tutorials and is available for free download.

The RIM user guide

Weed seed wizard

Integrated weed management hub

It has options for four crops, three pastures and 43 practices that include herbicide use and rates, timing of application, soil preparation, crop type, grazing and HWSC options.

Graphs can be produced and exported to other software programs for analysing ryegrass survivors, gross margins across 10 years, yield loss from competition and ryegrass seedbank levels.

Decision support - Weed Seed Wizard

Weed Seed Wizard can investigate the impact of a wide range of IWM strategies (such as grazing, HWSC, increased crop competition, rotation change and various seed set controls such as crop topping and hay making) on weed and weed seed numbers.

This national simulation tool was developed by DAFWA in partnership with the University of Western Australia, University of Adelaide, the New South Wales Department of Primary Industries and the Department of Agriculture Fisheries and Forestry in Queensland and supported by GRDC.

The user enters site-specific weather data and soil type, the weed species to be investigated and information about past and future weed management.

The model uses real weather data and gives an estimate of crop yield loss as a result of weed pressure from a range of species.

6.2 Major weeds in Western region

6.2.1 Annual rye grass

Annual ryegrass (*Lolium rigidum*) is one of the most serious and costly weeds of annual winter cropping systems in south-western Australia. Annual ryegrass is highly competitive and can compete with a crop as early as the two-leaf crop stage. It is a winter to spring growing weed that can emerge from late autumn through to early spring. The number of emergence flushes and the density of plants that emerge are related to initial seedbank levels and the frequency and amount of rainfall.

Why is it a major weed?

As one of the most serious and costly weeds in southern Australia's winter cropping systems, annual ryegrass produces an extremely high number of seeds per plant. Dense stands (>100 plants/m^2) can produce up to 45,000 seed per square metre under ideal conditions. Annual ryegrass is highly competitive and can compete with crops as early as the two-leaf crop stage. Annual ryegrass also is a host for the bacteria *Clavibacter* spp., which cause annual ryegrass toxicity (ARGT) and can be infected by ergot fungus.

Identification

Annual ryegrass is hairless and has bright green, narrow leaves. The leaves are shiny, especially on the back of the blade. It has a wide ligule, long auricles and the emerging leaf is folded. The base (below ground) is often reddish purple in colour and seedlings exude a clear sap when crushed.

Mature plants are erect and up to 900 millimetres (mm) in height (Photo 4).

Photo 4: *Mature ryegrass in a cereal crop at the Harrington's Wagin farm, WA, during the 2010 harvest.*

Source: GRDC

The inflorescence (flowering stems) are flat and up to 300 mm in length. Spikelets have 3–9 flowers and the husk is almost the same length as the spikelet (Photo 5).

Photo 5: *Annual ryegrass head.*

Source: DAFWA

Seeds are relatively flat, 4–6 mm long, 1 mm wide and straw-coloured, with the seed embryo often visible through the outer layers. They are held securely to the flower stem and significant force is needed to detach them either as individual seeds or as part of the flower stem.

Herbicide resistance

Many populations of annual ryegrass have developed resistance to both selective and non-selective herbicides. Repeated use of herbicides from the same mode-of-action group (particularly the high-risk Groups A and B) have lead to herbicide-

MORE INFORMATION

Tactics for IWM against Ryegrass in WA

Ryegrass Integrated Management

VIDEOS

WATCH: Managing herbicide resistant ryegrass with IWM.

resistant individuals. Annual ryegrass has developed resistance to the following mode-of-action herbicide groups in Western Australia.

- Group A — 'fops' (for example, diclofop-methyl)
- Group A — 'dims' (for example, sethoxydim)
- Group B — sulfonylureas (for example, chlorsulfuron and sulfometuron)
- Group B — imidazolinones (for example imazapic)
- Group C — triazines (atrazine and simazine)
- Group C — substituted ureas (for example, diuron)
- Group D — trifluralin
- Group M — glyphosate
- Group Q — triazoles (for exampe, amitrole)

There are now more than 23 confirmed cases of glyphosate-resistant ryegrass populations in Australia mostly from cropping paddocks. There are at least three populations recorded in WA. There has also been a recent case of resistance to paraquat in annual ryegrass been found in South Australia. [17]

6.2.2 Wild radish

Wild radish (*Raphanus raphanistrum*) is highly competitive in crops and can cause a yield loss of 10–90%. The fibrous stems of wild radish make harvesting difficult by choking the header comb, it is an alternative host for a number of pests and diseases and it can cause animal health problems when grazed.

Why is it a weed?

Wild radish is easily distributed as an impurity in hay, chaff and grain. Seed pods often break into segments similar in size to wheat seed, and removing the contamination can be quite difficult. Wild radish sheds pods before crop harvest, enabling it to persist in cropping systems.

Wild radish is very competitive because the seedlings establish rapidly and grow relatively fast. The fibrous stems of wild radish make harvesting difficult by choking the header comb.

Moisture levels of harvested grain can be affected. During years with late rains, when wild radish continues to grow and remains green after crop maturity, the moisture squeezed from the wild radish stems during harvest often raises the grain moisture content above acceptable storage levels. It has allelopathic activity and extracts and residues can suppress germination, emergence and seedling growth of some crops and weeds.

Wild radish is also an alternative host for a number of pests and diseases and can cause animal health problems.

Distinguishing features

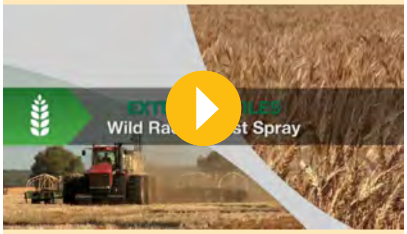
Wild radish is generally a winter and spring-growing annual that may grow up to 1.5m high (Photo 6). The cotyledons are heart-shaped and hairless with long stems. The first true leaves are irregularly lobed around the edges with one or more completely separated lobes at the base of the leaf blade.

17 Peltzer S. (2016). Annual ryegrass. DAFWA. https://www.agric.wa.gov.au/grains-research-development/annual-ryegrass?page=0%2C0

VIDEOS

WATCH: GCTV14: Early control wild radish.

WATCH: GCTV Extension files: Wild Radish – 1st spray.



WATCH: GCTV Extension files: Wild radish – 2nd spray.

WATCH: IWM: Weed seed bank destruction – wild radish seed.

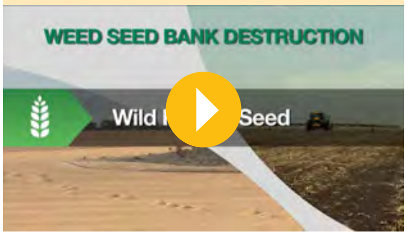


Photo 6: *Wild radish plants growing above the surrounding cereal canopy.*

Source: GRDC

The seedling develops into a flat rosette, the leaves of which do not have a distinct stalk. Erect branches covered with prickly hairs arise from near the base as the plant matures. The rosette of lobed leaves does not persist.

Lower stem leaves are covered with prickly hairs and deeply lobed, with a rounded terminal lobe. When crushed, these leaves have a strong turnip-like odour. Upper stem leaves become narrower, shorter and often undivided.

Flowers are in clusters on the ends of stem branches (Photo 7). They have four petals, which alternate with four sepals. The petals may vary in colour; yellow or white petals are more common than purple, pink or brown. Petals often have light or dark distinct veins. The seed pod is constricted between the seeds and does not split lengthwise.

Photo 7: *Flowering head of wild radish, a very serious weed in the Northern WA wheatbelt.*

Photo: M Williams, Source: GRDC

MORE INFORMATION

Tactics for IWM against Wild radish

Herbicide resistant Wild radish: take back control.

Wild radish management and strategies to address herbicide resistance

It breaks up into distinct segments when ripe and during threshing it is often broken up into single-seeded segments. Each pod usually has three to nine seeds, ovoid to almost globular, yellowish to reddish brown and covered with white bran-like scales. There is no seed in the beak of the pod.

Wild radish can be confused with wild turnip (*Brassica tournefortii*), charlock (*Sinapis arvensis*), turnip weed (*Rapistrum rugosum*) or garden radish (*Raphanus sativus*).

Herbicide resistance

Populations (mostly in WA) have developed resistance to herbicides in the mode-of-action (MOA) Groups B, C, F and I. Group B resistance is the most common, followed by Group F.

- Group B — sulfonylureas (for example, chlorsulfuron)
- Group B — sulfonamides (for example, metosulam)
- Group B — imidazolinones (for example, imazapic)
- Group C — triazines
- Group C — triazinones (for example, metribuzin)
- Group F — pyridinecarboxamides (for example, diflufenican)
- Group I — phenoxys (2,4-D) [18]

6.2.3 Wild oats

Wild oats (*Avena fatua* and *A. ludoviciana*) represent a large cost to cropping. Wild oats are highly competitive and when left uncontrolled can reduce cereal yields by up to 80%. Greatest yield loss occurs when the wild oat plants emerge at the same time as the crop.

Why is it a weed?

The annual cost to the Australian wheat industry of wild oats during 1999 was estimated to be $80 million, with $60 million being spent on herbicides and their application and $20 million in lost yield.

They produce a large number of seeds and up to 20,000 seeds/m^2 can be produced by uncontrolled infestations.

Wild oats avoid early herbicide applications as a proportion of the seeds germinate later than the crop.

Wild oats are easily spread as contaminants of grain, hay and machinery. Up to 75% of wild oat seed can be collected at harvest, with seeds being transported up to 250 metres (m) from the parent plant by the harvest operation. Delaying harvest can reduce seed movement in the paddock and grain sample, as the delay means a greater proportion of the wild oats seeds will have shattered.

Wild oats act as a host for a number of important cereal diseases including cereal cyst nematode (*Heterodera avenae*), stem nematode (*Ditylenchus dipsaci*), rhizoctonia (*Rhizoctonia solani*), crown rot (*Fusarium graminearum*) and root lesion nematode (*Pratylenchus neglectus*).

Distinguishing features

Wild oats have a large ligule with no auricles and the leaves tend to be hairy with a slight bluish hue (Photo 8). The emerging leaf is rolled. The seedling leaves are twisted anticlockwise, the opposite direction to wheat and barley. Wild oat seeds are usually dark but can vary through to cream. Hairiness of seeds also varies.

18 Peltzer S. (2016). Wild radish. DAFWA. https://www.agric.wa.gov.au/grains-research-development/wild-radish?page=0%2C0

Photo 8: *Mature wild oats in a cereal paddock.*

Source: DAFWA

Wild oats tend to grow in discrete patches at low to moderate densities (up to 100plants/m^2) and can be confused with brome grass in the seedling stage. All *Bromus* spp. have tubular leaf sheaths and hairy leaves and sheaths while wild oats exhibit a rolled sheath and few hairs on the leaves.

Herbicide resistance

Wild oats can easily develop resistance to herbicides. Group A herbicide resistance, predominately to 'fop' herbicides (for example, Topik®), has been present in Australian populations of wild oats since the mid 1980s (Photo 9). In Western Australia, wild oats are currently resistant to:

- Group A — 'fop' (for example, diclofop-methyl)
- Group A — 'dims' (for example, tralkoxydim)

In Australia, wild oats are also currently resistant to Group B - sulfonylureas (for example mesosulfuron) and Group Z (for example flamprop-m-methyl). [19]

Photo 9: *Group A resistant Wild oats on the inter-row of a cereal crop.*

Photo: E. Leonard.

Source: GRDC

MORE INFORMATION

Tactics for IWM against Wild oats.

19 Peltzer S. (2016). Wild oats. DAFWA. https://www.agric.wa.gov.au/crop-weeds/wild-oats?page=0%2C0

6.2.4 Brome grass

Brome grass (*Bromus diandrus* and *B. rigidus*) is one of the most competitive grass weeds in wheat. It shows drought tolerance, better tolerance of phosphorus deficiency and a better responsiveness to nitrogen than wheat. For this reason, addition of nitrogen to a crop can aggravate a brome grass problem. Brome grass contaminates grain, the seeds contaminate wool, damage hides and meat and cause injury to livestock by entering their eyes, mouth, feet and intestines.

Why is it a weed?

Brome grass is one of the most competitive grass weeds in wheat. It is drought tolerance, more tolerant to phosphorus deficiency and a better response to nitrogen compared with wheat. Hence, addition of nitrogen to a crop can aggravate a brome grass problem.

Brome grass contaminates grain and in pastures the seeds contaminate wool, damage hides and meat and cause injury to livestock by entering the eyes, mouth, feet and intestines. Left uncontrolled in fallow or pasture phases, brome grasses will host and carry over cereal diseases to new crops. These diseases include: ergot (*Claviceps purpurea* (Fr.) Tul.), take-all (*Gaeumannomyces graminis* (Sacc.) v. Arx & Oliv.), powdery mildew (*Erysiphe graminis* DC.), septoria glume blotch (*Leptosphaeria nodorum* Muller), black stem rust (*Puccinia graminis* Pers.), brown rust (*Puccinia recondita* Roberge ex Desm.), barley net blotch (*Pyrenophora teres* Drechsler), sharp eyespot (*Rhizoctonia solani* Kuhn), bunt (*Tilletia caries* (DC.) Tul.), cereal yellow dwarf virus, cereal cyst nematode (*Heterodera avenae* Woll.) and root-knot nematode (*Meloidogyne* spp.).

Seed production can range from 600 to more than 3000 seeds per plant. The ability to shed a large proportion of seed before crop harvest is another important characteristic that makes brome grass a major weed.

Distinguishing features

Both species have erect seedlings with dull, hairy leaves that display red–purple stripes following the leaf veins (Photo 10). At the seedling stage brome grass may be confused with wild oats (*Avena spp.*) because both possess hairs on the leaves and stems (Table 1).

Table 1: *Distinguishing characteristics of Bromus diandrus and B. rigidus.*

Character	***B. diandrus*** **(great brome)**	***B. rigidus*** **(rigid brome)**
Leaf appearance	10 mm wide leaves, which are rough and have some long hairs. The hairs on the leaf blade point upwards. There are usually prominent purple stripes on the leaf sheath.	Wide leaves with sparse hairs and very erect panicle branches.
Inflorescence appearance	The inflorescence is loose and nodding and spikelet branches are longer than the spikelets.	The inflorescence is compact and stiff. Spikelets are often heavily pigmented with reddish to black colouring. The spikelet branches are shorter than the spikelets.
Seed appearance	The hardened scar on the seed is rounded.	The hardened scar on the seed is acute.

Source: DAFWA

Photo 10: *The two main problem species of brome grass - Diandrus (left) and Rigidous (right).*

Source: GRDC

MORE INFORMATION

Tactics for IWM against Brome grass

Herbicide resistance

In WA, there are brome grass populations that have developed resistance to:

- Group B — sulfonylureas (for example, sulfosulfuron)
- Group B — imidazolinones (for example, imazapic and imazapyr).
- Group C — triazines (for example, simazine)[20]

6.3 Key weeds in Australia's cropping systems

Click on the weed name below to be taken to further information on this weed.

Annual ryegrass (*Lolium rigidum*)

Barley grass (*Hordeum* spp.)

Barnyard grasses (*Echinochloa* spp.)

Black bindweed (*Fallopia convolvulus*)

Bladder ketmia (*Hibiscus trionum*)

Brome grass (*Bromus* spp.)

Capeweed (*Arctotheca calendula*)

Doublegee (*Emex australis*)

Feathertop Rhodes grass (*Chloris virgata*)

Fleabane (*Conyza* spp.)

Fumitory (*Fumaria* spp.)

Indian hedge mustard (*Sisymbrium orientale*)

Liverseed grass (*Urochloa panicoides*)

Muskweed (*Myagrum perfoliatum*)

20 Peltzer S. (2016). Brome grass. DAFWA. https://www.agric.wa.gov.au/grains-research-development/brome-grass?page=0%2C0

Paradoxa grass (*Phalaris paradoxa*)

Silver grass (*Vulpia* spp.)

Sweet summer grass (*Brachiaria eruciformis*)

Turnip weed (*Rapistrum rugosum*)

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

Wild radish (*Raphanus raphanistrum*)

Windmill grass (*Chloris truncata*)

Wire weed (*Polygonum aviculare* and *Polygonum arenastrum*) [21]

6.4 Herbicides explained

Herbicides play a vital role in integrated weed management programs. Knowledge of the mechanisms and activity of herbicides will improve the impact and sustainability of herbicides as a weed management tactic (Table 2).

Chemical weed control options in triticale varieties are in general similar to those for wheat, although some differences in tolerances are important. In all states the DPI or its equivalent produce a recommended herbicide usage publication which should be consulted before using herbicides with triticale.

It is important that care is taken to ensure crop and weed tolerances based on the label recommendations are adhered to. Additionally, weather conditions, herbicide rates, water dilution rates, and adjoining crops status need to be assessed and managed correctly. Whilst a range of chemical are registered for use in both wheat and triticale, some herbicides are only legal for use in wheat. Additionally, some herbicides are only legal to use at specific crop stages in triticale. [22]

Table 2: *Types of herbicides and their effects on weeds.*

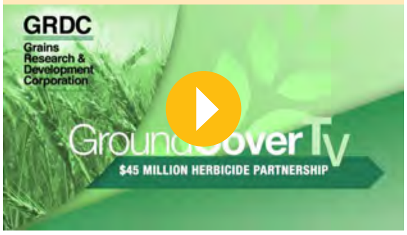
Type of herbicide	Effect
Translocated herbicides	move to the site of action via the transport mechanisms within the plant; the xylem and phloem. The xylem transports water and nutrients from the soil to growth sites and the phloem transports products of photosynthesis (for instance, sugars) to growth and storage sites. It may take up to two weeks for symptoms to develop on the target weeds depending on herbicide rate, conditions and species.
Contact herbicides	have limited movement within the plant, so complete coverage of the target is critical. Compared to translocated herbicides (for example, glyphosate), contact herbicides (for example, paraquat, oxyfluorfen, diquat and bromoxynil) tend to show symptoms rapidly, usually within 24 hours.
Selective herbicides	will kill target weeds and not desired plants (the crop or pasture) when applied at a specified application rate.
Non-selective herbicides	(also called knockdown herbicides) such as glyphosate or paraquat will damage most plants.
Residual herbicides	remain active in the soil for an extended period of time (months) and can act on successive weed germinations.

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

22 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

VIDEOS

WATCH: GCTV17: Herbicide partnership.



MORE INFORMATION

Herbicide uptake by plants

Disc seeding systems and pre-emergent herbicides

Type of herbicide	Effect
Non-residual herbicides	such as the non-selective paraquat and glyphosate, have little or no soil activity and 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	are terms that 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.
Herbicides mixtures and sequential applications	involve the application of more than one herbicide, usually to increase the spectrum of weed species controlled but also for resistance management. A mixture involves the application of multiple products in a single application. Where herbicides are antagonistic and cannot be mixed together in a single tank, they are applied sequentially.

Source: DAFWA

6.5 Pre-emergent herbicides

Triticale is competitive against weeds once established. A pre-emergent knockdown should be applied with limited options available post emergence. There are herbicide options against broad-leaf weeds. [23]

Ideally a non-selective knockdown should be used when sowing main season varieties to reduce the reliance on post-emergent herbicides. [24]

Stay up to date with available herbicides and instructions for application with the APVMA and PubCRIS websites.

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.

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.
- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [25]

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.

23 AGF Seeds. Triticale. https://agfseeds.com.au/triticale

24 Waratah see Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

25 Douglas A. (2016). Herbicides. DAFWA. https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2

6.5.1 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. 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.

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.

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.

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.

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. [26]

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.
- IBS rather than PSPE for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [27]

6.5.2 Tactical spray fallow in the Western region

Use of a tactical spray fallow in low rainfall areas of the WA grainbelt can reduce risks associated with seasonal variability, herbicide resistant weeds and growing non-profitable crops in poor years.

By strategically knocking down weeds in fallow paddocks during the summer months or at seeding time (Photo 11) - and keeping these paddocks clean from weeds until the next year's sowing period - vital soil moisture for the next 18 months is conserved for the subsequent crop.

This next crop should be healthier, have a lower weed burden, produce more grain yield and be more likely to generate a higher two-year gross margin than growing two low-yielding cereal crops.

Other benefits of this type of extended tactical fallow include:

- Increased plant available water (PAW) and soil mineral nitrogen (N) availability to crops
- A wider and more reliable sowing window
- Less weed-vectored pests, nematodes and diseases
- Reduced levels of rust disease inoculum (via interruption of the green bridge)
- Reduced levels of aphid-vectored diseases. [28]

26 Preston C. (2014). Understanding pre emergent cereal herbicides. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides

27 Haskins B. DPI NSW. Using pre-emergent herbicides in conservation farming systems. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

28 GRDC (2016). Hot topics: Tactical spray fallow in the western region. https://grdc.com.au/Media-Centre/Hot-Topics/Tactical-spray-fallow-in-the-western-region

MORE INFORMATION

Tactical spray fallow in the Western region

Photo 11: *An aerial image taken in June 2016 shows the scale of the Mingenew tactical fallow trial site that is supported by the GRDC's Regional Cropping Solutions Networks (RCSN) Geraldton and Kwinana East port zone groups in Western Australia.*

Source: GRDC

6.6 Post-plant pre-emergent herbicides

Post-sowing, pre-emergent herbicides use is when a pre-emergent herbicide is applied after sowing (but before crop emergence) to the seedbed. Application of pre-emergent herbicides pre-sowing and then incorporating them into the seed bed during the sowing process will often increase safety to crops because the sowing operation removes a certain amount of herbicide away from the seed row. This can conversely reduce weed control for the very same reason, as chemical is moved out of the seed row. In this case it is wise to include a water soluble herbicide into the mix aiming to have some herbicide wash into the seed furrow.

The preferred method of applying pre-emergent herbicides in conservation farming systems is by IBS, as crop safety is maximised, stubble remains standing to protect the seedbed, and soil disturbance is minimised.

Post-plant pre-emergent herbicides are primarily absorbed through the roots, but there may also be some foliar absorption (e.g. Terbyne®). When applied to soil, best control is achieved when the soil is flat and relatively free of clods and trash. Sufficient rainfall (20–30 mm) to wet the soil through the weed root-zone is necessary within 2–3 weeks of application. Best weed control is achieved from Pre-sowing, Pre-emergence application because rainfall gives the best incorporation. Mechanical incorporation pre-sowing is less uniform, and so weed control may be less effective. If applied pre-sowing and sown with minimal disturbance, incorporation will essentially be by rainfall after application. Weed control in the sowing row may be less effective because a certain amount of herbicide will be removed from the crop row.

6.6.1 Incorporation by sowing

Incorporation by sowing (IBS) is when a herbicide is applied just before sowing (usually in conjunction with a knockdown herbicide such as glyphosate and soil throw from the sowing operation incorporates the herbicide into the seedbed.

Application of pre-emergent herbicides pre-sowing and then incorporating them into the seed bed during the sowing process will often increase safety to crops because the sowing operation removes a certain amount of herbicide away from the seed row. This can conversely reduce weed control for the very same reason, as chemical is moved out of the seed row. In this case it is wise to include a water soluble herbicide into the mix aiming to have some herbicide wash into the seed furrow.

Two trials conducted in 2013 evaluating the crop safety and efficacy of registered residual herbicides for the control of ARG in wheat.

The majority of treatments were managed by the incorporation by sowing (IBS) approach. IBS specifies the use of narrow point tynes on the planting equipment. This approach helps to ensure sufficient soil is thrown across the inter-row space to effectively 'incorporate' the herbicide, plus it removes most of the herbicide treated soil from the planting furrow to improve crop safety. The negative consequence is that IBS generally provides poor weed control in the zone immediately around the planting row. In many cases, post sowing pre-emergent application (PSPE) is also being evaluated as it provides more uniform weed efficacy but requires herbicides or rates with improved crop safety together with reduced incorporation characteristics.

Take home messages

- The use of a disc planter for incorporation by sowing (IBS) of residual herbicides resulted in significantly reduced wheat emergence for all four herbicides evaluated
- The disc planter 'set-up' actually increased the risk of crop damage (Figure 1).
- These results reinforce the need to only use narrow point tynes when using residual herbicides with IBS recommendations

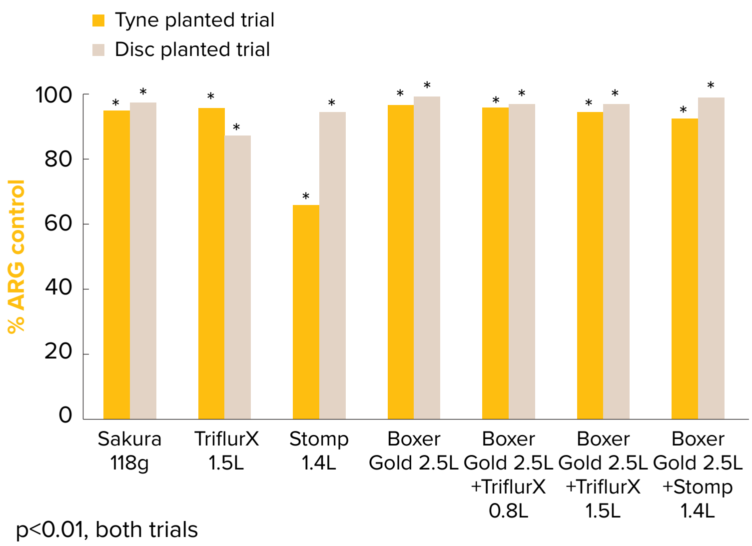


Figure 1: *Per cent annual ryegrass control based on counts (22/9/13, 94 days after planting) UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa * = significant ARG control compared to untreated within same trial.*

Source: GRDC

Efficacy summary

- High levels of ARG control were achieved by most IBS treatments
- The most consistent product were Boxer Gold or Sakura

- Weed control from Boxer Gold was significantly reduced in one of the two trials when applied by PSPE

Conclusions

This work was conducted due to commercial crop safety concerns arising from the use of residual herbicides at planting for ARG control. These two trials highlighted some key points:

1. Crop safety was significantly reduced when a disc planter was used for incorporation
2. The disc setup appears to have exaggerated crop safety issues by planting seed in an area with increased herbicide concentration
3. Observation suggested that small differences in planting depth may have impacted on crop safety in this scenario

This work reinforces some of the difficulties growers and agronomists face with the use of residual herbicides. Crop safety and efficacy are influenced by a range of factors including planting equipment, planting depth, soil type, stubble load together with rainfall quantity and timing. As an industry we need to have a more thorough understanding of the impacts from these (and perhaps other factors) to ensure we get the best from these important weed management tools. [29]

Stay up to date with available herbicides and instructions for application with the APVMA and PubCRIS websites.

6.7 In-crop herbicides: knock downs and residuals

6.7.1 Selective post-emergent herbicides

These products control weeds that have emerged since crop or pasture establishment and can be applied with little damage to the crop or pasture plants.

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 using selective post-emergent herbicides.
- The technique used for application must be suited for the situation in order to optimise control.
- Always use the correct adjuvant to ensure effective weed control.
- Selective post-emergent herbicides applied early and used as a stand-alone tactic have little impact on the weed seedbank.
- Choose the most suitable formulation of herbicide for each situation.

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29 Daniel R, Mitchell A, NGA. (2014). GRDC Update Paper: Pre-emergent herbicides; part of the solution but much still to learn. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn

- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors. [30]

6.7.2 Knockdown herbicides for fallow and pre-sowing control

Knockdown herbicides (or non-selective) kill all plants when used in sufficient quantities, under suitable environmental conditions.

Benefits

- Knockdown herbicides effectively kill weeds and are cost-effective.
- Use of knockdown herbicides can improve the timeliness of sowing.
- Use of knockdown herbicides rather than cultivation will reduce the risk of erosion, improve soil structure and improve plant available soil water content.

Issues

- Consider the suitability of herbicide use for fallow or pre-sowing weed control by assessing environmental conditions.
- Stressed weeds will not be adequately controlled by knockdown herbicides.
- Overuse of knockdown herbicides will select for resistance.
- Suitable meteorlogical conditions for spraying can be limited, especially for weed control over the summer fallow.

6.7.3 Double knockdown

'Double knock' refers to the sequential application of two weed control tactics applied in such a way that the second tactic controls any survivors of the first tactic. A common combination is glyphosate followed by paraquat or paraquat/diquat.

Benefits

- Double knockdown delays or prevents the development of glyphosate resistance.
- Using a double knockdown strategy reduces the number of (potentially resistant) weeds to be controlled in crop.
- Excellent weed seedling control is achieved.

Issues

- Glyphosate should be applied first, followed by paraquat or paraquat/diquat.
- The timing between applications will vary depending on the main target weed species.
- Consider the main target weed species when choosing what herbicides to use in the double knockdown.
- Double knockdown is more expensive than a single herbicide application.
- Seasonal conditions will influence the scale of on-farm implementation (as a double knockdown takes more time than a single application). [31]

Stay up to date with available herbicides and instructions for application with the APVMA and PubCRIS websites.

Key points for in-crop herbicide application:

- Knowledge of a product's translocation 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.

30 Douglas A. (2016). Herbicides. DAFWA. https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2

31 Douglas A. (2016). Herbicides. DAFWA https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C1

- 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.
- Appropriate conditions for spraying are always important. [32]

In-crop herbicides will normally require a different set of nozzles compared to those used in summer fallow spraying and application of pre-emergent herbicides.

In-crop post-emergent herbicides should be applied as an upper-end medium to lower-end coarse droplet spectrum depending on the particular herbicide being used.

Remember that this must be combined with the relevant application volume to get enough droplets per square centimetre on the target to achieve good coverage. You must also match the nozzles to your spray rig, pump and controller and desired travel speed.

Operate within the recommended ground speed range and apply the product in a higher application volume. The actual recommended application volume will vary with the product and situation, so read the label and follow the directions.

How to get the most out of post-emergent herbicides:

Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical.

Consider the growth stage of the crop.

- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species were historically in the paddock and the resistance status of the paddock
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or, for some chemicals, cloudy/sunny days. This is especially pertinent
- for frosts with grass-weed chemicals.
- Use the correct spray application:
- Consider droplet size with grass-weed herbicides, water volumes with contact chemicals and time of day.
- Observe the plant-back periods and withholding periods.
- Consider compatibility if using a mixing partner.
- Add correct adjuvant. [33]

MORE INFORMATION

GRDC In-crop herbicide use Factsheet.

6.7.4 Fenceline weeds in the Western region

About one quarter of glyphosate resistant populations within broadacre cropping situations across Australia come from fencelines and other non-cropping areas of the farm.

Along paddock borders, where there is no crop competition, weeds can flourish and, if not controlled, set lots of seed (Photo 12). The traditional approach has been to treat these weeds with glyphosate to keep borders clean but after 20-odd years this option is now failing and paddock borders are becoming a significant source of glyphosate-resistant weed seed.

32 GRDC Factsheets: In-crop herbicide use. (2014). https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/08/grdc-fs-incropherbicideuse

33 WeedSmart. Post-emergents. http://www.weedsmart.org.au/post-emergents/

Photo 12: *With minimal crop competition, weeds can thrive along paddock borders.*

Source: GRDC

The control options used will generally be determined by whether the border in question needs to be kept bare or if vegetation is beneficial. In some situations, cultivation can be used to kill the weeds and provide a firebreak, but on light soils this may pose an erosion risk and mowing or slashing may be safer options. Another possible tactic is to continue using herbicides but to ensure that a clean-up operation is carried out before any survivors can set seed.

Planting the crop right to the fence and then baling the outside lap and spraying with a knockdown herbicide to kill any weeds and provide a firebreak is another option.

Spring is a traditional time for controlling weeds along the borders however the weeds present in spring are too large to be effectively treated with contact herbicides. Using a slasher with a spray nozzle is a better option for these survivors.

If possible, a move to herbicide control in autumn will provide better control and reduce the risk of herbicide resistant weeds setting seed.

Another option is to apply a high rate of diquat and paraquat to small weeds, followed with paraquat 14 days later.

Early treatment with a residual herbicide such as bromacil mixed with a knockdown such as paraquat also has a beneficial effect on seed set.

Weeds growing in and adjacent to head ditches and tail drains in irrigation areas are also of significant concern. Glyphosate resistant barnyard grass poses a high risk because the seed travels easily in irrigation water and can rapidly infest the crop area.

Fenceline trials in WA have investigating herbicide treatment alternatives to glyphosate for weed control in crop margin areas along fencelines, firebreaks and boundaries.

Results from 11 trials over three years showed that a single application of bromacil plus paraquat in May or June provided complete control of all weeds at all sites.

While bromacil is relatively expensive, only one application was needed to control all weeds, including summer weeds, for at least one year. But this highly residual herbicide needs to be used carefully and only where there are no trees or risk of wind erosion.

Where the use of bromacil is inappropriate, two control times are often needed – once early in the year, followed by another later in the year. Tank mixes of residual herbicides plus a knockdown give the best control for the first application.

In trials in 2014, an application in May of either simazine plus Alliance® (paraquat plus amitrole) or simazine, 2,4-D and paraquat, followed by a second application of atrazine and paraquat in August, gave very good control.

The addition of Alliance® improved control, especially where there were broadleaf weeds.

Other research outcomes included:

- Slashing followed by a spray later in the season provided good control in situations where weeds were actively growing and there was good spray coverage
- Glyphosate can still be used but intensive monitoring and complete seed set control is required to prevent resistance from developing
- The use of cultivation as a control option generally did not work well in this series of trials but has potential in the right situation

Be sure to adhere to herbicide labels and use full label rates when spraying weeds. [34]

6.7.5 Pre-harvest herbicide use

The application of herbicides late in the season to prevent weeds setting seed or to desiccate crops must be carried out with caution and in line with herbicide label recommendations. It is essential to check if these practices are acceptable to buyers, as in some situations markets have extremely low or even zero tolerance to some pesticide and herbicide residues.

Key points:

- **Correct usage:** Product labels must be followed and withholding periods adhered to for all herbicides. Off-label use without a permit is not allowed and can result in grain being unsaleable.
- **Residues:** Pre-harvest applications to crops increase the risk of detectable herbicide residues in harvested grain, potentially leading to breaches of maximum residue limits (MRLs). MRLs vary according to herbicide, crop and market and these need to be understood.
- **Registration:** Diquat, including Reglone®, is the only registered herbicide for preharvest weed control in barley. However, growers must be aware that some maltsters have certain restrictions on pre-harvest use of herbicides. Consult with buyers before use. weedmaster®DST® is now registered for pre-harvest use in canola and with higher use rates in wheat. It is the only glyphosate formulation registered for use in canola and for higher use rates in wheat.
- **Food safety:** Growers and their advisers need to be aware of the implications of their herbicide applications and the role they play in ensuring food health safety and in protecting the grain industry.
- **Be responsible:** Stewardship must be taken seriously by all sections of the grain value chain.

MORE INFORMATION

Pre-harvest herbicide use: Stewardship for pre-harvest application of herbicides in winter crops – Factsheet.

6.8 Application and conditions for spraying

Herbicides can be applied by a variety of means including boom sprayers (Photo 13), aerial spraying, misters, blanket wipers, rope wick applicators, weed seekers and back-pack sprayers. This section reviews the different types of methods to apply herbicides including nozzles and calibration of equipment.

34 GRDC. (2015). Hot topics: Fenceline weeds in the Western region. https://grdc.com.au/Media-Centre/Hot-Topics/Fenceline-weeds-in-the-western-region

MORE INFORMATION

Choosing boom spray nozzles for particular conditions

Nozzles for spraying herbicides

VIDEOS

WATCH: Nozzle Selection.

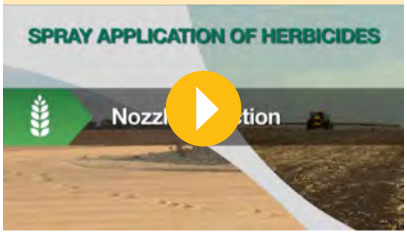


Photo 13: *Boom sprayers are one of many herbicide application methods available to growers.*

Photo: Brad Collis, Source: GRDC

6.8.1 Boom sprayer

A boom sprayer is the most common type of apparatus for applying herbicides in broadscale farming. A sprayer has many components, the most important being the nozzles, which split the herbicide into many small droplets that are projected through the air to the target. The nozzle is the only component of the sprayer that directly determines the effectiveness of spraying. All other components are necessary to position the nozzles and provide them with a continuous supply of herbicide at the correct pressure. Correct nozzle selection and operation are critical for successful spraying.

6.8.2 Misters

Misters are a useful but imprecise way of applying herbicides to large areas quickly. They rely on wind to drift the herbicide. If the wind is too light or the spraying speed too high, the swath width will decrease, possibly causing overdosing and wasted chemical. If the wind is too strong or gusty, it increases the swath width, which will reduce the chemical application rate and increase the risk of damage from spray drift.

6.8.3 Blanket wipers

Blanket wipers are made of a vertical strip of material attached to a horizontal frame. The vertical strip, or blanket, acts as the wiping surface making direct contact with the target weed. This equipment has been developed as an alternative to rope wick applicators. A non-selective herbicide is generally used with successful weed control dependant on the height differential between crop and weed. Wipers are used in broadacre application to control radish or mustard in lupins or chickpeas or to 'top' grasses in pasture. Units have been designed to fit all terrain bikes and hand held equipment has been developed for back yard and environmental use to treat weeds such as cape tulip, Paterson's curse, Guildford grass, arum lily, fressia and bracken fern. Herbicide can be selectively applied to these plants without damaging pasture legumes or native seedlings in revegetation areas. The best time to wipe weeds in crops is September to early October when the weeds are flowering and are 20–30 cm taller than crop or pasture plants.

6.8.4 Rope wick applicators

Rope wick applicators consist of a series of ropes impregnated with a non-selective herbicide, usually glyphosate. They are not widely used, but they can be useful for the control of tall weeds in a crop or pasture. Normal spraying with a non-selective herbicide would not be possible in this situation, however a rope wick applicator can be moved above the crop or pasture and wipe the herbicide only onto the taller weeds, hence selective control is obtained. This technique has been partially successful for controlling cape tulip, docks, rushes, thistles and bracken in pasture.

MORE INFORMATION

Spot spraying, chipping hand roguing and wiper technologies

Because they can only operate at slow speeds and the ropes are very expensive, rope wick applicators have not gained wide acceptance.

6.8.5 Detection technology

Detection technology (for example, Weedseeker and Weedit) uses infrared and near infrared light to detect green weeds and sprays only green plants in paddocks. In action, light-emitting diodes (LEDs) point two different light sources, infrared and near infrared, towards the ground. Green weeds have a different reflective signature to stubble or soil. The system can operate at speeds up to 20 kilometres per hour (km/h), requiring a stable boom to aid operational efficiency.

6.8.6 Calibration of spray equipment

The importance of having your spray equipment accurately set up and calibrated cannot be overstressed. Huge losses can be incurred through incorrect herbicide application. These can range from total failure of the herbicide to kill the weeds, to the extreme where an overdose of herbicides kills both weeds and crop, and may even leave residues in the soil. Even if overdosing does not cause crop damage, the extra cost of the herbicide applied unnecessarily can be significant.

Calibration method

There are many methods for calibrating, usually involving calculations. A simplified method designed for boom sprayers with nozzles at 50 cm spacings is summarised below.

- Measure the output of each nozzle for one minute. This should already have been done when choosing an even set of nozzles.
- Measure the combined output of all nozzles and divide by the number of nozzles. This gives average output per nozzle in millilitres per minute (mL/min).
- Decide on a speed of travel for spraying.
- Measure out a distance of 100m and record the time taken to cover the distance with the spray unit. It is important to calculate the speed on a surface similar to that being sprayed. You can calculate it by: speed (km/h) = 360 ÷ time (seconds) taken to travel 100m.
- Calculate the output using the following formula:

$$\text{Output in L/ha} = \frac{\text{Average output of a nozzle (mL/min)} \times 60}{\text{Nozzle spacing (cm)} \times \text{speed of spraying (km/h)}}$$

To calculate the amount of herbicide needed for each tank of spray, the tank size (volume) must be known. Dividing the tank size by the output (L/ha) gives the number of hectares that can be sprayed with each tank. Multiply the rate of herbicide required per hectare by the number of hectares that can be sprayed per tank to get the amount of herbicide added to each tank.

Example:

- Sprayer with a 1000 L tank; output 50 L/ha
- Number of hectares sprayed/tank: 1000/50 = 20ha
- If the rate of herbicide application is 2 L/ha, the amount of herbicide added to each tank is 2 x 20 = 40 L

To better judge the appropriate rate of herbicide and water requires continuous monitoring of conditions and results to establish the causes of failure or success. To achieve this you must keep records of every day's spray operations, and assessment of herbicide performance.

Herbicide performance is influenced by weather, soil moisture, growth stage and density of the weeds, herbicide rate, water rate, droplet size, and growth stage of the crop.

Record all of these for each paddock each time you use the sprayer. Weather conditions should be recorded at intervals during the spraying operation and for the preceding and following days.

A good marking system is essential to prevent overlap or missed areas when spraying. Overlap of the spray swath results in areas being sprayed twice, which waste both herbicides and time.

Missed areas result in uncontrolled weeds, which can reduce yield, provide seeds for future generations or contaminate crops.

Misters are a useful but imprecise way of applying herbicides to large areas quickly. They rely on wind to drift the herbicide. If the wind is too light or the spraying speed too high, the swath width will decrease, possibly causing overdosing and wasted chemical. If the wind is too strong or gusty it increases the swath width, which will reduce the chemical application rate and increase the risk of damage from spray drift. [35]

MORE INFORMATION

Herbicide application - Nozzles

6.8.7 How to reduce spray drift

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 coexist, 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 (Photo 14).

Photo 14: *Reading the product label is even more important than before as requirements may have changed as the labels of currently registered pesticides are being reviewed to include comprehensive instructions on managing spray drift.*

Photo: Emma Leonard

Source: GRDC

35 Peltzer S. (2016). Herbicide application. DAFWA. https://www.agric.wa.gov.au/grains/herbicide-application?page=0%2C0

All grass herbicides labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions. 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

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'.
- Don't 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 is the least damaging. [36]

Small droplets have a large surface area in relation to their mass. They are therefore easily blown by wind. The higher the wind speed at the time of spraying, the more likely are droplets to be blown away from the target.

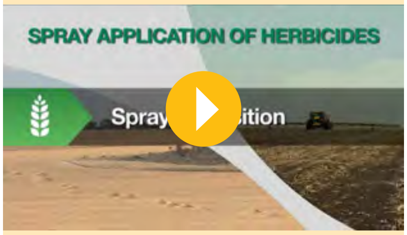
Moreover, the liquid carrier may evaporate in hot dry conditions, thus reducing the droplet size in transit from spray nozzle to target.

All spraying systems produce a range of droplet sizes, although the range produced by Controlled Droplet Applicators is much narrower than that of conventional hydraulic nozzles. Therefore, spray drift is impossible to eliminate but it may be reduced to acceptable levels. This can be done by avoiding spraying in adverse

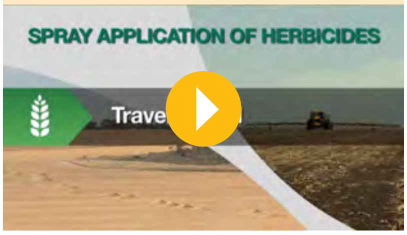
36 Storrie A. (2015). Reducing herbicide spray drift. DPI NSW. http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift

VIDEOS

WATCH: Spray deposition.



WATCH: Travel Speed.



conditions (for example, during high winds and temperature inversions) and adjusting the boom spray operation.

As a rule of thumb, droplets with a mean diameter of 250µm (0.25 mm) or larger do not normally drift. So, by aiming for large droplet sizes, drift is reduced.

Smaller droplets are, however, more economical. They give better coverage for a given volume of spray and provide better penetration of foliage and attachment to leaf surfaces.

Large droplets have other disadvantages; they give an uneven cover of the target plant surface and tend to bounce off leaves. They are also less likely than smaller droplets to stick to vertical surfaces and the underside of leaves.

A recent development with nozzle design is air induction or injection. The air induction nozzle draws air into the system using a venturi action and then forms large droplets that are filled with air. These droplets because they are large do not drift as much as the small droplets. When they hit a target they then shatter into a large number of smaller droplets. This way the there is less drift, coverage of the target is still achieved when the large drops shatter into many smaller ones and the air filled drops do not bounce once they hit a target.

Misters and boom sprays produce many small droplets. Misters should never be used up-wind close to susceptible crops. Drift from boom sprays may be minimised by manipulation of the sprayer nozzles (for example, air induction nozzles), spraying height, reduced spraying pressure and tractor speed. Airfoils above booms have also directed the droplets downwards towards the targets.

A long droplet trajectory from nozzle to crop increases the chance of droplets evaporating. To minimise droplet travelling distance, choose wide spray angle flat fan nozzles (110°) rather than the narrow fan angle, for example, 80°, angled backwards at 45° and run the boom as low as possible above crop height.

Vapour drift is a problem with certain chemicals, mainly the volatile ester formulations. The spray vaporises from the soil or plant surface after spraying and may drift many kilometres to damage susceptible crops. This mainly occurs under hot, dry conditions. It can be avoided by use of amine formulations or low volatile esters.

Weather conditions affect both droplet drift and vapour drift. Avoid hot dry conditions and windy days. The best time to spray is in cool, moist conditions in the morning or early evening, but not when the weather is calm because then temperature inversion is likely which can lead to unpredictable spread of chemical droplets. A slight breeze blowing away from the susceptible crop is ideal. [37]

Ensure that herbicide application methods conform to state Legislation, the Aerial Spraying control Act, 1966 and ARRPA Regulations, 1976.

6.8.8 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.

37 DAFWA. (2016). Avoiding spray drift. https://www.agric.wa.gov.au/residues-crops/herbicide-application-legal-aspects?page=0%2C0

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, say 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'. [38]

MORE INFORMATION

Practical tips for spraying – GRDC Fact sheet

DAFWA- Herbicide drift

6.9 Herbicide tolerance ratings, NVT

Some studies indicate that triticale may be less tolerant to some herbicide cocktails than wheat. Newer herbicides as well as pesticides are now being released with recommendations for use on triticale in many parts of the world. [39]

NVT herbicide tolerance trails undertaken in NSW between 1996–2015 give an indication of triticale's response to a range of herbicides.

There is anecdotal evidence that triticale tolerates many of the same herbicides as wheat. In 2004 and 2005, trials in the US tested the tolerance of three triticale varieties (AC Alta, AC Ultima, and Pronghorn) with four herbicides registered for wheat: florasulam + MCPA ester, clodinafop-propargyl, thifensulfuron-methyl/tribenuron-methyl, and sulfosulfuron-methyl + 2,4-D ester. Herbicides were applied at the label rate (1×) for wheat and twice (2×) that rate. Crop injury, plant height, biomass, and seed yields were quantified. Neither florasulam + MCPA ester, clodinafop-propargyl, nor thifensulfuron-methyl/tribenuron-methyl at 1× or 2× use rates significantly injured triticale. Sulfosulfuron-methyl + 2,4-D ester reduced triticale height at the 1× and 2× rates, as well as reduced biomass and yield at the 2× rate. Florasulam + MCPA ester, clodinafop-propargyl, and thifensulfuron-methyl/tribenuron-methyl do not cause significant crop injury and can be used for weed control in spring triticale, but sulfosulfuron-methyl + 2,4-D ester is not recommended for use in triticale. [40]

Within many broadacre crop species, cultivars have been found to vary in sensitivity to commonly used herbicides and tank mixes, thereby resulting in potential grain yield loss and reduced farm profit. With funding from GRDC and state government agencies across Australia, a series of cultivar × herbicide tolerance trials are conducted annually.

38 Storrie A. (2015). Reducing herbicide spray drift. DPI NSW. http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift

39 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

40 Raatz, L., Hills, M., McKenzie, R., Yang, R. C., Topinka, K., & Hall, L. (2011). Tolerance of spring triticale (× Triticosecale Wittmack) to four wheat herbicides. *Weed Technology*, *25*(1), 84–89.

The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species including wheat, barley, triticale, oats, lupin, field pea, lentil, chickpea and faba bean. The intention is to provide data from at least two years of testing at the time of widescale 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. This occurs with the use of registered herbicides applied at label rates under good spraying conditions at the appropriate crop growth stage.

To provide growers with clear information about the herbicide interactions of a variety for their region, four regionally based, herbicide-tolerance screening projects have been established.

The four projects have recently been combined under a national program.

6.10 Potential herbicide damage effect

Excessive herbicide treatments may limit germination in triticale. The successive effect of several herbicide variants (isoxaben, chlorsulfuron) on the germination and plant growth of triticale cultivars has been explored. Germinative energy and germinating power of winter triticale seeds, obtained from plants treated with herbicide, were generally lower, in particular for the isoproturon and chlorsulfuron variants. [41]

6.10.1 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)). 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. sulfonylurea, triazines etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [42]

Make sure to read product labels for plant-back periods.

For example:

- Lusta – Registered in triticale, cereal rye, wheat, and oats. Activity occurs through root and foliar uptake. Plant-back recommendations on alkaline soils for triticale and wheat are none.
- Ally - Registered in triticale, wheat, barley and cereal rye. Activity by foliar translocation but also root absorption after rain. [43]

41 Sławomir, S., & Robert, M. (1996). Successive effect of herbicides on triticale seed germination and plant growth. In *Triticale: Today and Tomorrow* (pp. 743–747). Springer Netherlands.

42 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

43 Lenaghan L. Residual herbicides Group B and C carry-over. http://www.croppro.com.au/resources/BCGGroupBResidual_herbicides(2)(1).pdf

6.10.2 Herbicide residues in soils – are they an issue?

The move to conservation tillage and herbicide-tolerant crop cultivars means that many farmers are relying on herbicides for weed control more than ever before. Despite the provision of plant-back guidelines on herbicide product labels, site-specific factors such as low rainfall, constrained soil microbial activity and non-ideal pH may cause herbicides to persist in the soil beyond usual expectations. Because of the high cost of herbicide residue analysis, information about herbicide residue levels in Australian grain cropping soils is scarce.

In addition, little is known about how herbicides affect soil biological processes and what this means for crop production. This is especially the case for repeated applications over multiple cropping seasons. In Australia, herbicides undergo a rigorous assessment by the Australian Pesticides and Veterinary Medicines Authority (APMVA) before they can be registered for use in agriculture. However, relatively little attention is given to the on-farm soil biology – partly because we are only now beginning to grasp its complexity and importance to sustainable agriculture. Although a few tests are mandatory, such as earthworm toxicity tests and effects on soil respiration, functional services provided by soil organisms such as organic matter turnover, nitrogen cycling, phosphorus solubilisation and disease suppression are usually overlooked.

GRDC recently co-funded a five year project (DAN00180) to better understand the potential impacts of increased herbicide use on key soil biological processes. This national project, co-ordinated by the NSW Department of Primary Industries with partners in Western Australia (WA), South Australia (SA), Victoria (Vic) and Queensland (Qld), is focussed on the effect of at least six different herbicide classes on the biology and function of five key soil types across all three grain growing regions.

Main conclusions:

- Glyphosate, trifluralin and diflufenican are routinely applied in grain cropping systems and their residues, plus the glyphosate metabolite AMPA, are frequently detected at agronomically significant levels at the commencement of the winter cropping season.
- The risk to soil biological processes is generally minor when herbicides are used at label rates and given sufficient time to dissipate before re-application.
- However, given the frequency of glyphosate application, and the persistence of trifluralin and diflufenican, further research is needed to define critical thresholds for these chemicals to avoid potential negative impacts to soil function and crop production. [44]

MORE INFORMATION

Herbicide residues in soils, are they an issue?

6.10.3 Avoiding residual herbicide damage

When researching the residual activity and cropping restrictions following herbicide application, the herbicide label is the primary source of information and it should be read thoroughly.

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. For example, chlorsulfuron (Lusta®) is used in wheat and barley, but it can remain active in the soil for several years and damage legumes and oilseeds. A real difficulty for growers lies in identifying herbicide residues before they cause a problem. 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

44 GRDC. (2016). GRDC Update Papers: Herbicide residues, are they an issue? https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/herbicide-residues-in-soils-are-they-an-issue-northern

with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease.

An option for assessing the potential risk of herbicide residues is to conduct a bioassay involving hand planting small test areas of crop into the field in question.

How can I avoid damage from residual herbicides?

Select a herbicide which is necessary for the weed population you have. Make sure you consider what the recropping limitations may do to future rotation options.

Read the herbicide label including the fine print.

Chemical users are required to keep good records, including weather conditions, but in the case of unexpected damage good records can be invaluable, particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock).

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.

Be wary of compounding a residue problem by planting a herbicide resistant crop and spraying with more of the same herbicide group. You may get around the problem with residues in the short term, only to be faced with herbicide resistant weeds in the longer term. [45]

6.10.4 Conditions required for herbicide 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.

6.11 Herbicide resistance

It is important to differentiate between herbicide resistance and herbicide tolerance.

Herbicide resistance is the inherited ability of an individual plant to survive a herbicide application that would kill a normal population of the same species. Whereas, herbicide tolerance is the inherent ability of a species to survive and reproduce after herbicide treatment at a normal use rate. There is no selection involved (through herbicide application) because the species is naturally tolerant.

Over 25 weed species in Australia currently have populations that are resistant to at least one herbicide 'mode of action' (MOA) group (Photo 15).

45 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Environment and Primary Industries Victoria.

Photo 15: *Wild radish resistance is an emerging problem, but recent research by is finding control of the weed is effective with a two-spray approach, with the first spray at the two to three leaf stage, followed by a second spray at the five to six leaf stage.*

Photo: Simon Craig, Source: GRDC

Herbicide resistance is normally present at very low frequencies in weed populations before the herbicide is first applied. Variation exists within every population, with some individuals having the ability to survive the herbicide application.

A weed population is defined as resistant when a herbicide that once controlled the population is no longer effective (sometimes an arbitrary figure of 20% survival is used). The proportion of herbicide resistant individuals will rise due to selection pressure in situations where one herbicide MOA group is applied repeatedly.

Herbicide resistance is permanent in weeds and their progeny with dominant 'target site' resistance. With cessation of the use of that herbicide MOA group, the ratio of dominant target site resistant to susceptible individuals will remain the same – only the total number of weeds present can be reduced. Weeds with this type of resistance do not exhibit a fitness penalty.

How does a weed become resistant to a herbicide?

There are three major ways in which resistance may arise within a weed population:

1. Pre-existing resistance: Within any weed population there may be some plants that already contain a rare change in a gene (or genes) that enable them to survive the application of a particular herbicide that would normally kill this species. Genetic variation may alter physiological traits that enable herbicide uptake, translocation and activation at the site of action. Alternatively, changes may influence the plant's ability to detoxify herbicides, or enable transport to a site within the plant where the herbicide is not lethal. Each time the herbicide is applied, susceptible plants die and those with resistance survive.
2. Importation of resistance: It is possible that resistance may not be present in the population initially, but is introduced as a weed contaminant in crop seed or fodder, on machinery or on/in animals. This is particularly important for 'rarer' forms of resistance such as glyphosate resistance.
3. Natural dispersal: Weed seeds can also be spread by wind and water. Pollen can also be dispersed great distances although the percentage remaining viable at

MORE INFORMATION

[Commonly used herbicides resistance terms]

[GRDC Herbicide resistance factsheet – Western region]

distances greater than 10m is low. Floodwater also has the potential to move a wide range of weed seeds over large distances.

6.11.1 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 3 and Figure 2). 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 3: *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

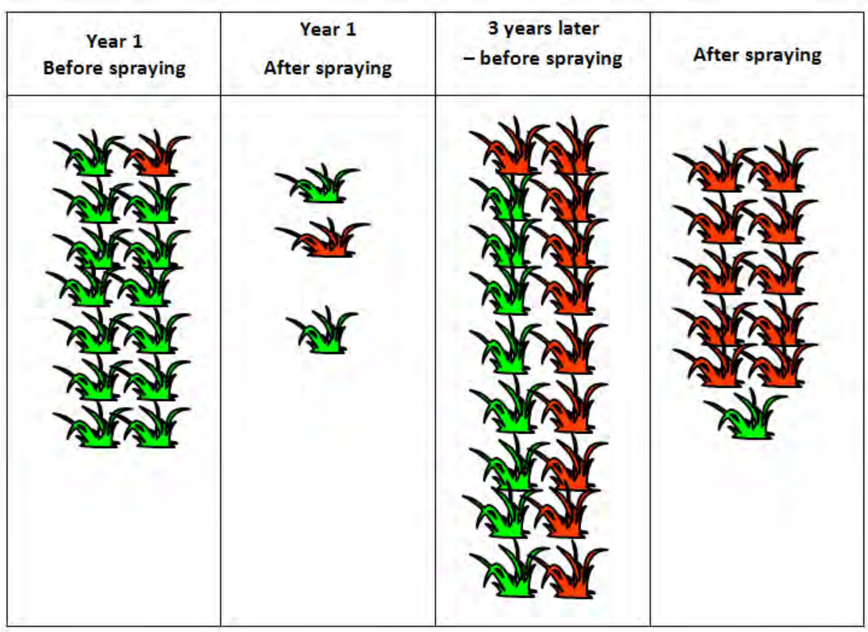


Figure 2: *How a weed population becomes resistant to herbicides.*

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 4. Aim to include as many as possible of the risk decreasing factors in your crop and weed management plans.

Table 4: *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

The online glyphosate resistance toolkit enables growers and advisors to assess their level of risk for developing glyphosate-resistant weeds on their farm.

MORE INFORMATION

Australian glyphosate resistance register.

6.11.2 Options for herbicide resistance testing

There are a number of different methods of testing for herbicide resistance. Tests can be performed in situ (in the paddock during the growing season), on seed collected from the suspect area or by sending live plant samples to a testing service.

Resistance testing

This can be conducted on-farm or by a commercial resistance testing service.

In-situ testing

An in-situ test can be performed following herbicide failure in a paddock. The test should be done at the earliest opportunity, remembering that the weeds will be larger than when the initial herbicide was applied. Test strips should be applied using herbicide rates appropriate to the current crop growth stage and weed size, plus a double rate. The test strips should only be applied if the weeds are stress free and actively growing. To more accurately assess the level of control, conduct weed plant counts before and after application. Green or dry plant weights can be calculated for more accurate results.

Herbicide resistance seed tests

Seed tests require collection of suspect weed seed from the paddock at the end of the season. This seed is generally submitted to a commercial testing service.

There are two commercial seed testing services in Australia

- Peter Boutsalis, Plant Science Consulting
- John Broster, Charles Sturt University, +61 (0)2 6933 4001

Approximately 3000 seeds of each weed (an A4-sized envelope full of good seed heads) is required for a multiple resistance test. This equates to about one cup of annual ryegrass seed and six cups of wild radish pods.

Syngenta herbicide resistance Quick-Test™

The Syngenta herbicide resistance Quick-Test™ (QT) uses whole plants collected from a paddock rather than seeds, eliminating the problem of seed dormancy and enabling a far more rapid turnaround time. In addition, the tests are conducted during the growing season rather than out of season over the summer. A resistance status result for a weed sample is possible within four to six weeks. The QT, which was developed by Dr Peter Boutsalis while working for Syngenta in Switzerland, is patented in Australia.

For each herbicide to be tested, 50 plants are required. To reduce postage costs, plants can be trimmed to remove excess roots and shoots. Upon arrival at the testing service, plants are carefully trimmed to produce cuttings and transplanted into pots. After appearance of new leaves (normally 5–7 days), plants are treated with herbicide in a spray cabinet. The entire procedure, from paddock sampling to reporting results, takes between 4–6 weeks, depending on postage time and the herbicides being tested. Unlike paddock tests, the QT is performed under controlled conditions, so it is not affected by adverse weather conditions. The age of the plants is also less critical to the testing procedure. Trimming the plants prior to herbicide application means that herbicides are applied to actively growing leaves, thus mimicking chemical application to young seedlings. The Quick-Test™ has been used to test resistance in both grass and broadleaf weed species. During testing, both known sensitive and resistant biotypes are included for comparison.

Quick-Tests can be done with Peter Boutsalis, Plant Science Consulting.

6.11.3 Weedsmart- 10 point plan

WeedSmart, an industry-funded herbicide sustainability initiative, has developed a 10 Point Plan for implementing IWM systems.

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.

MORE INFORMATION

Strategic risk management factsheet

Farm business management factsheet

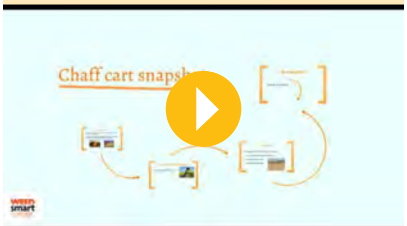
RIM model

VIDEOS

WATCH: Act now: Plan your weed management program

VIDEOS

WATCH: Chaff carts 101



WATCH: Capture weed seeds at harvest: Harrington seed destructor

WATCH: Strategic narrow windrow burning

WATCH: The art of narrow windrow burning

WATCH: Chaff funneling onto tramlines

- Be strategic and committed—herbicide resistance management is not a 1-year decision.
- Research and plan your WeedSmart strategy.
- You may have to sacrifice yield in the short term to manage resistance—be proactive.

A couple of areas to consider include:

- Understanding the biology of your weeds
- Being consistent – every successful WeedSmart practice can reduce the weed seed bank over time
- Being strategic and committed – herbicide resistance management is not a one-year decision
- Being proactive – you may have to sacrifice yield in the short term to manage resistance

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 new Harrington Seed Destructor. (Photo 16)
- 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.

Photo 16: *Harrington weed seed destructor at work in the paddock.*

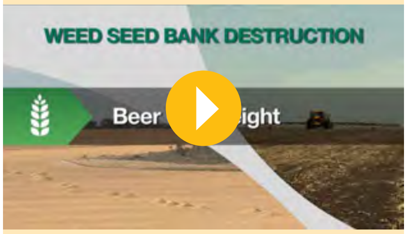
Source: GRDC

For information on harvest weed-seed control and its application, see Section 12: Harvest.

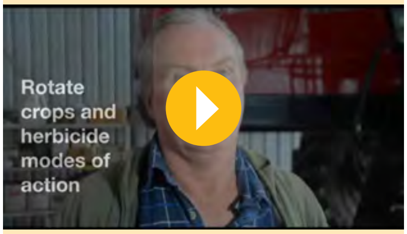
VIDEOS

WATCH: Capture weed seeds at harvest: Bale Direct System

WATCH: IWM: Weed seed vdestruction—Beer can height



WATCH: Crop rotation with Colin McAlpine



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

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.

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

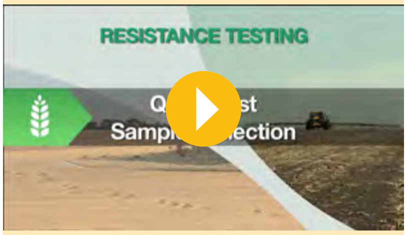
AHRI researcher Dr. Roberto Busi found that ryegrass receiving below the rate Sakura® evolved resistance not only to Sakura® but to Boxer Gold® and Avadex® too.

Imagine developing these multiple resistant, monster weeds just because you cut the rate!

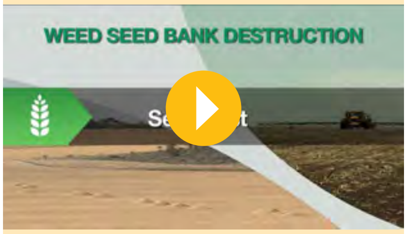
- Use best management practice in spray application.
- Consider selective weed sprayers such as WeedSeeker or WeedIt.

VIDEOS

WATCH: IWM: Resistance Testing—'Quick-Test' sample collection



WATCH: IWM: Seed test—What's involved



WATCH: Don't cut the rate

WATCH: Don't automatically reach for glyphosate

WATCH: Manage spray drift

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.

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.

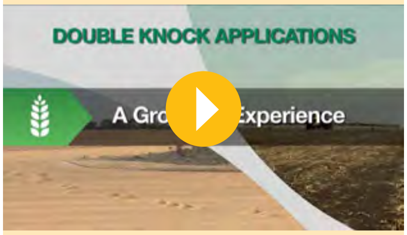
- It is easier to control weeds before the crop is planted.
- Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
- A recent Australian Herbicide Resistance Initiative (AHRI) survey showed that 73% of grower-saved crop seed was contaminated with weed seed.

VIDEOS

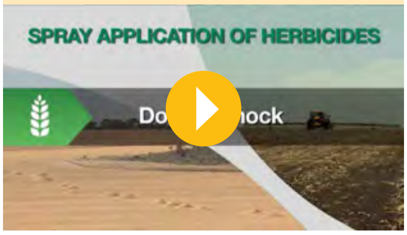
WATCH: Plant clean seed into clean paddocks with clean borders

WATCH: Best results with double-knock tactic

WATCH: Double-knock application—a grower's experience



WATCH: Spray application of herbicides—Double-knock



- The density, diversity and fecundity of weeds are generally greatest along paddock borders and areas such as roadsides, channel banks and fence lines.

9. Use the double-knock technique.

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 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, we recommend that growers contact their local agronomist.

The following steps are then recommended:

1. Consider the possibility of other common causes of herbicide failure by asking:
2. Was the herbicide applied in conditions and at a rate that should kill the target weed?
3. Did the suspect plants miss herbicide contact or emerge after the herbicide application?
4. Does the pattern of surviving plants suggest a spray miss or other application problem?
5. 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?
6. Has the uncontrolled species been successfully controlled in the past by the herbicide in question or by the current treatment?
7. Has a decline in the control been noticed in recent years?
8. Is the level of weed control generally good on the other susceptible species?

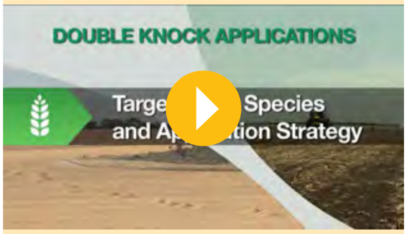
If resistance is still suspected:

1. Contact our crop and food science researchers via the Customer Service Centre 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. [46]

46 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

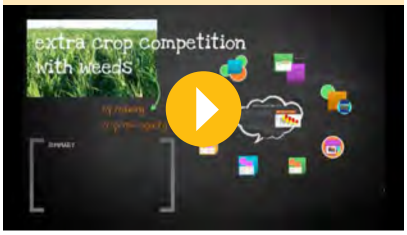
WATCH: Double knock applications: target weed species and application strategy



WATCH: Learn to think outside the drum

WATCH: Crop competition—Increasing wheat seeding rate

WATCH: Crop competition—Row spacing



MORE INFORMATION

CropLife Australia

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

Cotton Catchment Communities CRC (Weedpak)

Insect control

Key messages:

- Triticale varieties are affected by only a few insect pests. [1]
- Triticale has the same insect predators during growth as other cereals but in general fewer insect control measures are required with the exception of grain storage insects.
- Triticale is vulnerable to grasshoppers, aphids, armyworms and cutworms.
- 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.
- For current chemical control options refer to the Pest Genie or Australian Pesticides and Veterinary Medical Authority (APVMA).

Risks from insect damage in triticale are similar to those for wheat. Triticale is vulnerable to grasshoppers, aphids, armyworms and cutworms.

Management practices for these insects are the same as for other cereals. These practices should be applied only when continual scouting indicates that the problem has reached an economic threshold for control. [2]

Earthmites (red-legged and blue oat mites) can be problem in early growth and chemical control may be necessary depending on insect numbers/damage. Aphids may occur in late winter/spring and whilst usually not causing major damage themselves they do transmit BYDV and this may warrant control in severe infestations.

Monitor seedling crops for lucerne flea, red legged earth mite and blue oat mite. Seek local advice to determine if application of insecticide is warranted and ensure grazing withholding periods are met. Aphids can infest early sown crops and then again in spring. Early in the season they can spread viral disease while in spring they can cause yield damage. Seek local advice on thresholds and management options. [3]

In the US it has been recommended to replace early sown wheat with triticale because of its greater resistance to insect pests. [4]

Research in Europe suggests that later sowing may help to limit insect damage to triticale,[5] however, the efficacy of this practice would need to be tested in Australian cropping systems.

> *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

7.1.1 Insect pests of winter cereals

The risk of insect infestation to crops depends on a number of factors (Table 1). Particular insect pests impact crops at different growth stages (Table 2).

1 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

2 Alberta Agriculture and forestry. (2016). Triticale crop protection. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10572

3 Waratah Seed Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

4 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

5 Krusteva, H., & Karadjova, O. (2011). Impacts of triticale crop sowing date on the insect pest species composition and damage caused. *Bulgarian Journal of Agricultural Science*, *17*(4), 411–416.

Table 1: *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).
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.*

Pest	Crop stage			
	Emergence	**Vegetative**	**Flowering**	**Grainfill**
Wireworm	Damaging	Present		
Cutworm	Damaging			
Black headed cockchafer	Damaging	Present		
Earth mites	Damaging	Present		
Slugs, snails*	Damaging			
Brown wheat mite		Damaging		
Aphid	Present	Damaging	Present	Present
Armyworm		Present	Present	Damaging
Helicoverpa armigera				Damaging

Present in crop but generally not damaging

Crop susceptible to damage and loss

* Snails are also a grain contaminant at harvest

Source: IPM Guidelines

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.

VIDEOS

WATCH: Integrated Pest Management.

Insecticide resistance

- RLEM has been found to have high levels of resistance to synthetic pyrethroids such 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. [6]

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 identificaion, you need to know where on the plant to look and what is the best time of day to get a representative sample.
- **Monitoring frequency and pest focus** should be directed at crop stages likely to incur economic damage. Critical stages may include seedling emergence and flowering/grain formation.
- **Sampling technique** is important to ensure 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 shoud also be investigated. The relative proportion of hotspots in a field must be kept in perspective with less heavily infested areas.

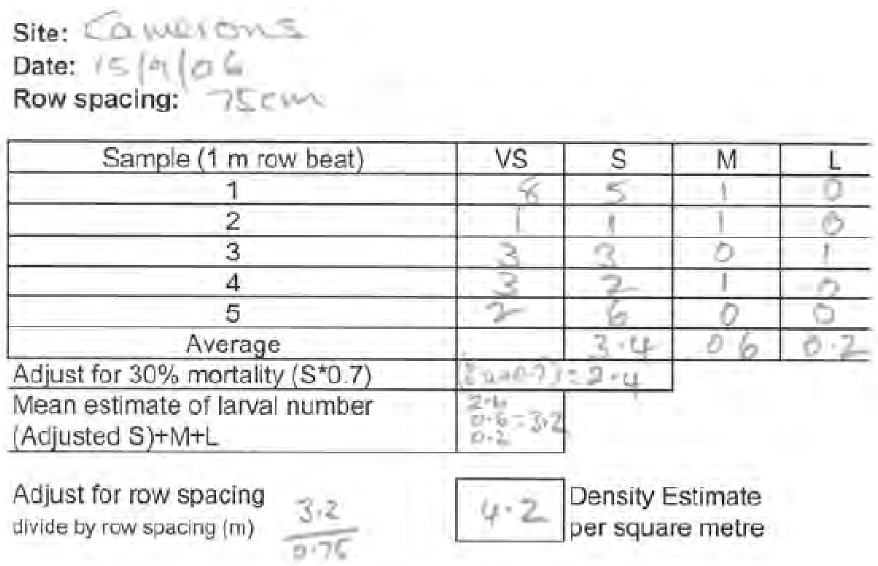
Keeping good records

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
- 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.

6 IPM Guidelines. Winter cereals. GRDC and DAFF. http://ipmguidelinesforgrains.com.au/crops/winter-cereals/



Site: Camerons
Date: 15/4/06
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): 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
- 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.
- 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 suface 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 it 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.

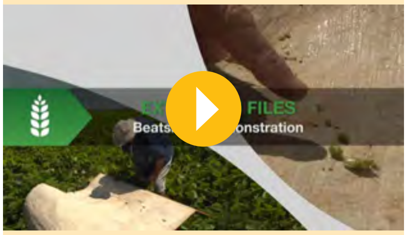
MORE INFORMATION

IPM Guidelines website.

IPM Guidelines for Monitoring tools and techniques.

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.

- **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. [7]

Photo 1: *Sweep-netting for insects (left) and use of a beatsheet (right).*

Source: DAFWA and The Beatsheet

For pest identification see the A-Z pest list or consult the GRDC Insect ID: The Ute Guide.

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. [8]

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.

7 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

8 GRDC. Apps. https://grdc.com.au/Resources/Apps

VIDEOS

WATCH: GCTV20: Russian wheat aphid – recommendations for ongoing treatment.

WATCH: Integrated pest management to combat the Russian wheat aphid.

MORE INFORMATION

Russian Wheat Aphid – PIR SA

Biosecurity Alert - WA

7.3 Aphids

Aphids are occasional pests of cereal crops in Western Australia, however, they can also spread barley yellow dwarf virus that reduces cereal yield. The two main species are corn aphid and oat aphid. [9]

7.3.1 Russian wheat aphid warning

Western Australian grain growers are urged to check cereal crops and grassy weeds for aphids and damage symptoms following the detection of the exotic Russian wheat aphid (*Diuraphis noxia*) in South Australia, Victoria and New South Wales.

Russian wheat aphid (Photo 2) is a major pest of wheat, barley and some grasses (*Poaceae*), which can cause significant yield losses.

Russian wheat aphid is not in WA. [10]

Photo 2: *Russian wheat aphid.*

Source: GRDC

As of 24 August 2016 RWA had not been detected in Western Australia but it is highly likely that RWA will arrive in the state at some time in the future. [11]

As a precaution, it is very important that growers, agronomists and consultants remain vigilant.

7.3.2 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 2). Adults may be

9 DAFWA. (2015). Diagnosing cereal aphids. https://www.agric.wa.gov.au/mycrop/diagnosing-cereal-aphids

10 DAFWA. (October, 2016). Biosecurity alert – Russian wheat aphid. https://www.agric.wa.gov.au/barley/biosecurity-alert-russian-wheat-aphid

11 DAFWA. 2017 Barley variety guide for Western Australia. https://grdc.com.au/resources-and-publications/all-publications/publications/2017/01/barleyvarietyguide

MORE INFORMATION

[Oat or Wheat aphid - cesar](#)

[Corn aphid - cesar](#)

winged or wingless and tend to develop wings when plants become overcrowded or unsuitable. [12]

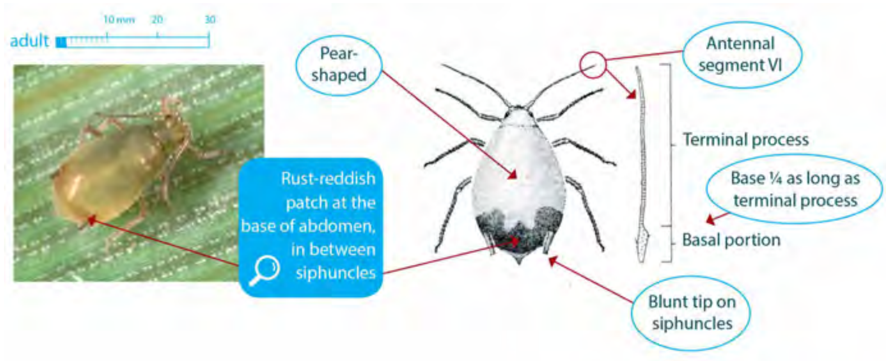


Figure 2: *Distinguishing characteristics of oat or wheat aphids.*

Source: Bellati et al. 2012 in Cesar

7.3.3 Corn aphid

Corn aphids are introduced and 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 3). 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. [13]

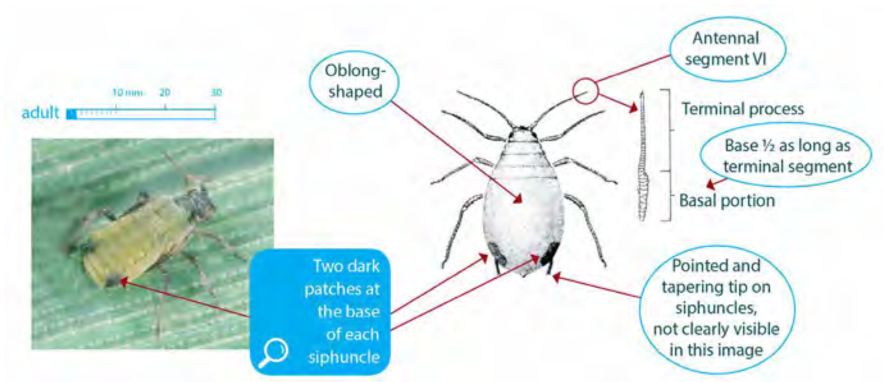


Figure 3: *Distinguishing characteristics of corn aphids.*

Source: Bellati et al. 2012 in Cesar

7.3.4 Symptoms

There may be no obvious symptoms while aphids are feeding and causing direct damage. Heavily infested plants may turn yellow and may be covered in a sugary honeydew produced by the aphids and on which black sooty moulds may develop.

12 Umina P, Hangartner S – cesar. (2015). Oat aphid. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

13 Umina P, Hangartner S – cesar. (2015). Oat aphid. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Corn-aphid

Much larger yield and quality losses can be sustained when crops are also infected with yellow dwarf virus. Refer to 'See also' section for further information on this virus. [14]

7.3.5 Damage caused by pest

Adult and nymph aphids suck sap with large populations limiting grain yield and size, especially winter and spring infestations.

Aphid feeding can cause direct damage, in the absence of the plant virus; barley yellow dwarf virus (BYDV), by reducing yields by up to 10% and by reducing seed size.

Damaging populations may develop in potentially high-yielding crops (2.5 t/ha or more).

Direct feeding damage occurs when colonies of aphids develop on stems, leaves and heads, from the seedling stage through to head filling.

The degree of damage depends particularly on the percentage of tillers infested, the number of aphids per tiller and the duration of the infestation. [15]

7.3.6 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 cereals
- Corn aphid – inside the leaf whorl of the plant – cast skins indicate their presence
- Grain aphid – colonises the younger leaves and ears of cereals
- 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.

Young wingless aphid nymphs develop through several growth stages, moulting at each stage into a larger individual. Plants can become sticky with honey-dew 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.

7.3.7 Thresholds for control

Spraying with an approved insecticide is worthwhile if 50% of cereal tillers have 15 or more aphids.

14 Coutts B, Micic S. (2016). Aphid feeding damage to cereal crops. DAFWA. https://www.agric.wa.gov.au/barley/aphid-feeding-damage-cereal-crops

15 Coutts B, Micic S. (2016). Aphid feeding damage to cereal crops. DAFWA. https://www.agric.wa.gov.au/barley/aphid-feeding-damage-cereal-crops

16 IPM Guidelines. (2016). Aphids in winter cereals. http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-winter-cereals/

Crops sprayed before Zadok's growth stage 30 (start of stem elongation) should be checked again 3–4 weeks after spraying as aphids may re-establish and build up again to threshold levels. [17]

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.

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. [18]

Aphid populations can decline rapidly, which may make control unnecessary. In many years aphid populations will not reach threshold levels.

7.3.8 Management of insect pest

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.

Cultural control

Sowing resistant cereal varieties is the most effective method of reducing losses. 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. [19]

Biological control

Parasitic wasps, ladybirds, lacewing and hoverfly larvae can provide useful biological control of aphid feeding damage at low aphid densities.

When aphids are in moderate to high densities, these predators and parasites are usually unable to control an increasing population, although given the right conditions certain fungi may kill a large proportion of the population over a short period of time.

17 Coutts B, Micic S. (2016). Aphid feeding damage to cereal crops. DAFWA. https://www.agric.wa.gov.au/barley/aphid-feeding-damage-cereal-crops

18 Umina P, Hangartner S – cesar. (2015). Oat aphid. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

19 Umina P, Hangartner S – cesar. (2015). Oat aphid. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

If predators are present use 'soft' insecticides such as pirimicarb that selectively kill aphids and leave predators intact. [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 5 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]

MORE INFORMATION

Aphids – economic considerations for management

7.4 Cutworm

Cutworms are plump, smooth caterpillars, of several moth species. They feed on all crop and pasture plants, damaging them near the ground. The caterpillars hide under the soil or litter by day. When mature, they pupate in the soil.

Cutworm caterpillars are plump and smooth, growing to about 40 mm long, but they usually cannot be seen as they hide under the soil or litter by day. Often they can be located by scratching the surface near damaged plants where they can be seen curled up in a defensive position (Photo 3).

20 Coutts B, Micic S. (2016). Aphid feeding damage to cereal crops. DAFWA. https://www.agric.wa.gov.au/barley/aphid-feeding-damage-cereal-crops

21 IPM Guidelines. (2016). Aphids in winter cereals. http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-winter-cereals/

Photo 3: *Cutworm larva in typical curled position when disturbed.*

Source: cesar

Triticale has had mixed response to cutworm damage in Australia. Trials in south-west WA found that triticale that had been attacked by cutworms four weeks after sowing, could regenerate quickly. [22]

In southern New South Wales, cutworms were reported to have caused severe damage to several germinating triticale crops. The damage observed was quite patchy, with some areas suffering 100% plant death. Most problems were observed in paddocks that had weeds and stubble over summer, while 'clean' paddocks that were cropped in previous years typically had few problems. Prolonged autumn green feed is likely to have allowed caterpillars to develop to a large size by the time crops started to emerge. Chemical control was required in the worse affected paddocks, which were re-sown recovered well. [23]

Caterpillars with a pink tinge belong to the pink cutworm, *Agrotis munda*, which has caused widespread damage in agricultural areas north of Perth. The dark grey caterpillars of the Bogong(þ moth, *Agrotis infusa*, have been extremely damaging in most parts of the agricultural areas from time to time. Large numbers of patterned caterpillars belonging to different genera, *Rictonis* and *Omphaletis*, have also been found attacking cereals in agricultural areas.

Adult cutworms are stout-bodied moths with patterned wings. They fly very well and may be seen on window panes at night as they are attracted to lights. [24]

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 4).

22 Johnstone C. (2011). Triticale variety demonstration. Online farm trials. http://www.farmtrials.com.au/trial/10587

23 McDonald G, Govender A & Umina P. PestFacts south-eastern Issue No. 3 – 21st May 2010. Cutworms. **cesar** pty ltd. http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2010/pestfacts-issue-no-3-21st-may-2010/cutworms/

24 Micic S. (2016). Cutworm: pests of crops and pastures. DAFWA. https://www.agric.wa.gov.au/pest-insects/cutworm-pests-crops-and-pastures

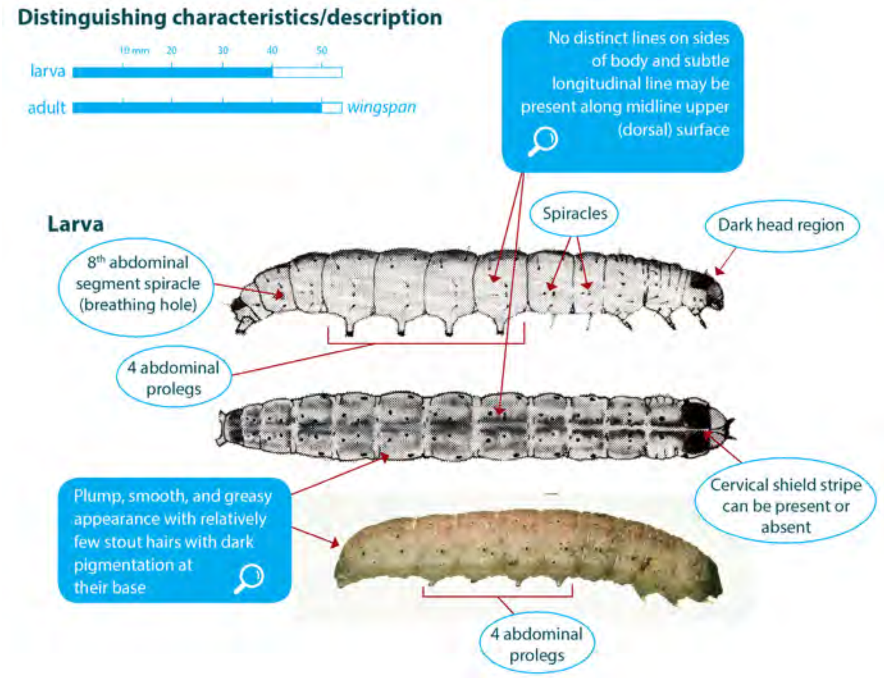


Figure 4: *Distinguishing characteristics of the cutworm.*

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 5). 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.

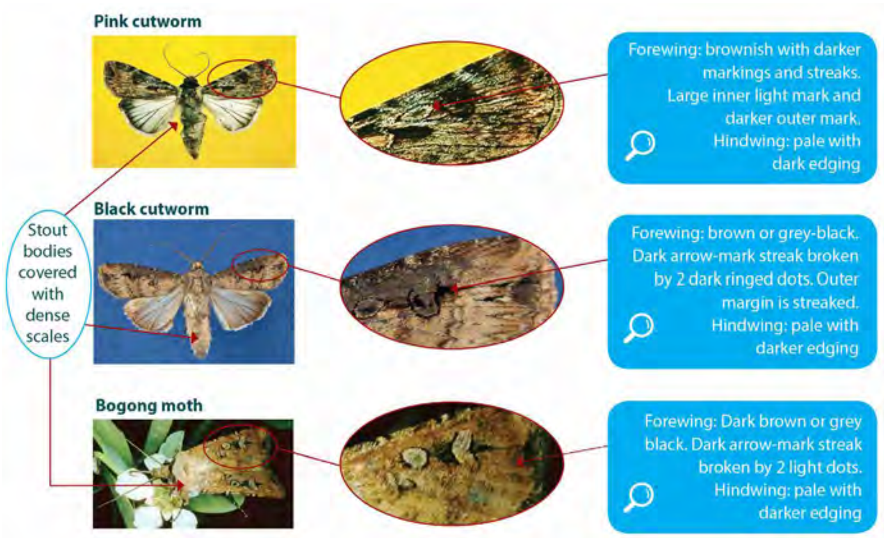


Figure 5: *Distinguishing characteristics of the adult forms of the pink, black and common cutworm.*

Source: Bellati et al, 2012 in cesar

7.4.1 Damage caused by cutworms

All crop and pasture plants are attacked by cutworms. They are most damaging in autumn when large caterpillars (>20 mm) transfer from summer and autumn weeds onto newly emerged crop seedlings. Whole paddocks of cereal seedlings may be destroyed or severely thinned early in the season. Pastures may be attacked at any time during the season but damage usually goes unnoticed. Irrigated crops may be attacked at any time of the year.

When small, the caterpillars feed on the surface tissues of the tender foliage (Figure 6), but as they grow they assume their typical cutworm 'felling' activity. The surface feeding may be confused with damage caused by lucerne flea and the more serious damage may be attributed to webworm. [25]

Figure 6: *Pink cutworm damage to the plant and paddock.*

Source: cesar

7.4.2 Thresholds for control

Treatment of cereals and canola is warranted if there are two or more larvae per 0.5 m of row.

7.4.3 Managing cutworms

Key points:

- Cutworms are easily controlled by insecticides.
- Biological control agents, including fly and wasp parasites, disease organisms and predatory beetles, continually reduce cutworm numbers but cannot be relied on to give adequate control. [26]

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 will also prey upon cutworms.

25 Micic S. (2016). Cutworm: pests of crops and pastures. DAFWA. https://www.agric.wa.gov.au/pest-insects/cutworm-pests-crops-and-pastures

26 Micic S. (2016). Cutworm: pests of crops and pastures. DAFWA. https://www.agric.wa.gov.au/pest-insects/cutworm-pests-crops-and-pastures

MORE INFORMATION

[Cutworm – economic considerations for management]

[Cutworm - cesar]

Cultural

As autumn cutworm populations may be initiated on crop weeds or volunteers in and around the crop, removal of this green bridge 3–4 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. [27]

7.5 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. [28] 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 the south-west of WA, southern NSW, on the east coast of Tasmania, the south-east of SA and throughout Victoria. 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.

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 7). 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.

27 Hangartner S, McDonald G, Umina P. (2015). Cutworm. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cutworm

28 GRDC. (2013). Ground cover supplement – emerging issues with diseases, weeds and pests.

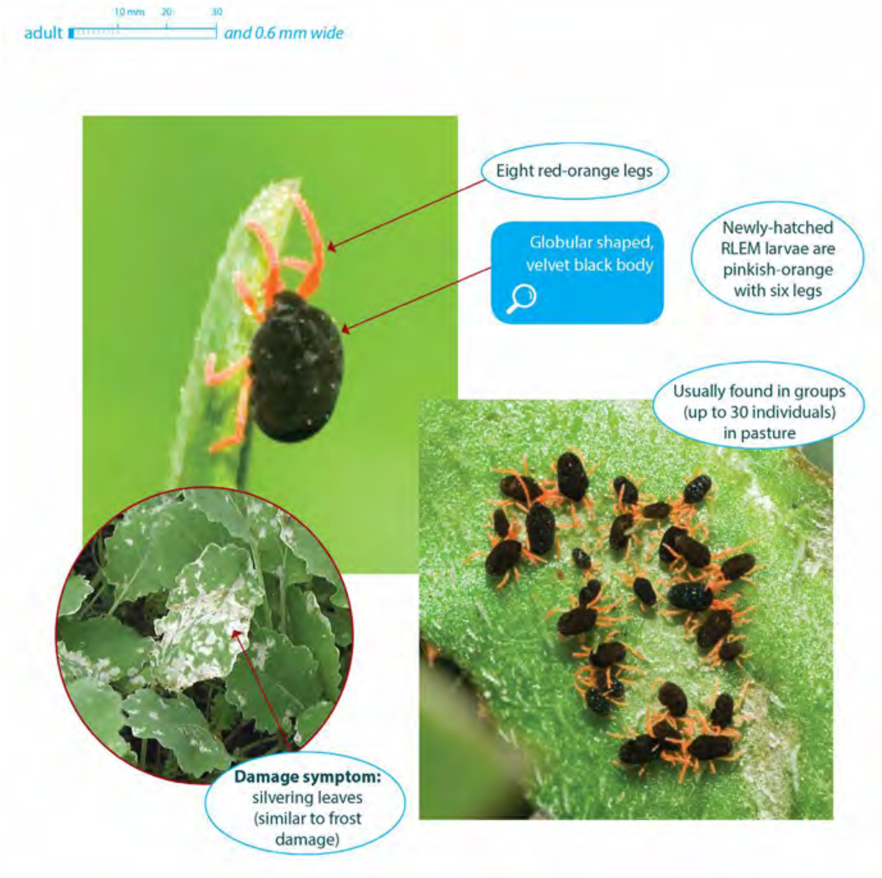


Figure 7: *Distinguishing characteristics of RLEM.*

Source: Bellati *et al.* 2012 in cesar

7.5.1 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.

7.5.2 Managing RLEM

Key points:

- Spray only if you need to. RLEM have been detected that have resistance to synthetic pyrethroids. Rotate chemical groups in and between seasons, as this will help to reduce resistance occurring.

- Use insecticide seed treatments for crops and new pastures with moderate pest pressure rather than spraying whole paddocks. This allows for smaller quantities of pesticide to be used that will directly target plant feeding pests.
- Control weeds before seeding, particularly in late autumn or winter sown crops where RLEM are likely to hatch before seeding. At least one week of bare soil can "starve out" most of the mite population before crops are sown.
- Control weeds in the crop and along fencelines that provide habitat for mites. A weed free crop will have few mites and over-summering eggs to carry through to the following season.
- Controlled grazing of pasture paddocks that will be cropped next year will reduce mite numbers to levels that are almost as effective as chemical sprays. Sustained grazing of pastures throughout spring to maintain them at levels below 2 tonnes per hectare. Feed On Offer (FOO) (dry weight) will restrict mite numbers to low levels.
- Apply insecticides to paddocks that are to be cropped during spring to prevent RLEM populations producing over-summering eggs. This will minimise the pest population for the following autumn. TIMERITE® is a free package that provides a date in spring for a spray application to stop female RLEM from producing over-summering eggs.
- Look at your cropping rotations to decrease reliance on pesticides. The risk is generally highest if paddocks have been in long term pasture (with high levels of broad-leafed plants) where mite populations have been uncontrolled. Lower risk paddocks that generally do not require mite control are often those which follow a weed free cereal or chickpea crop. [29]

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.

29 DAFWA. (2015). Diagnosing redlegged earth mite. https://www.agric.wa.gov.au/mycrop/diagnosing-redlegged-earth-mite

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 canola, 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.

MORE INFORMATION

Earth mites (Blue oat and RLEM) – economic considerations

Redlegged Earth Mite – cesar

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]

7.6 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 New South Wales 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 Western Australia, Victoria, New South Wales, South Australia and eastern Tasmania. There are three main species of blue oat mite; *Penthaleus major*, *Penthaleus falcatus* and *Penthaleus tectus*. These species differ in their distributions.

Adult BOM are 1 mm in length and approximately 0.7–0.8 mm wide, with 8 red-orange legs. They have a blue-black coloured body with a characteristic red mark on their back (Figure 8). 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.

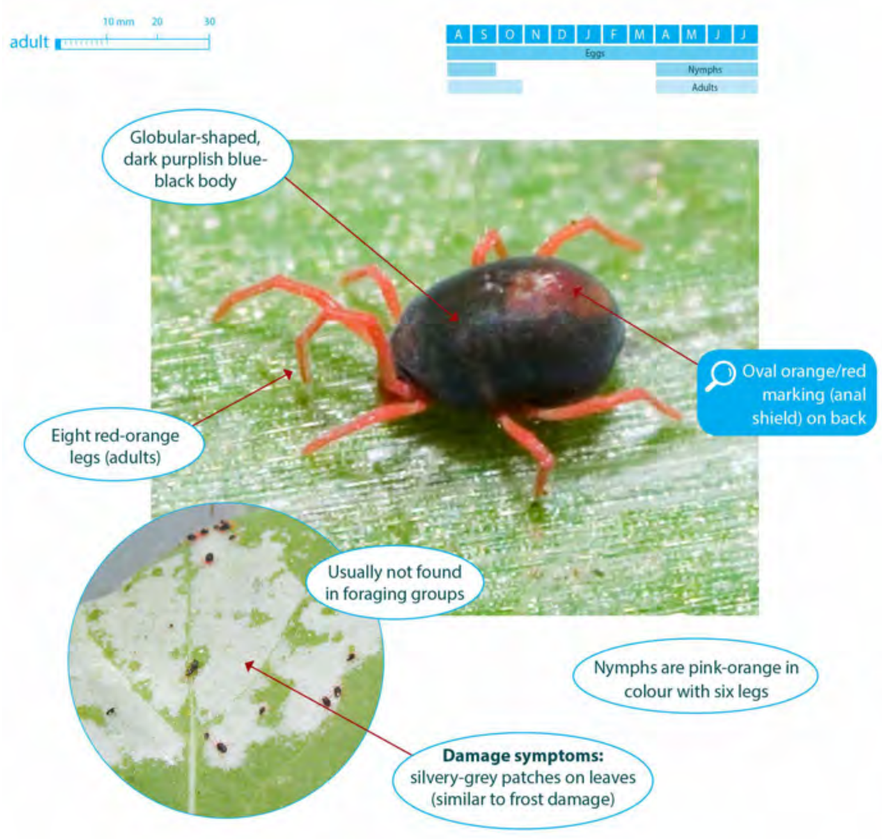


Figure 8: *Distinguishing characteristics of Blue oat mite.*

Source: Bellati et al, 2012 in cesar

30 Umina P. (2007). Redlegged earth mite. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/?a=223443

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. [31]

7.6.1 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. BOM are most damaging to newly establishing pastures and emerging crops, greatly reducing seedling survival and retarding development.

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. [32]

7.6.2 Managing Blue oat mite

Key points:

- Blue oat mites have higher natural tolerance to a range of pesticides. Ensure pesticide sprays are applied at registered rates.
- To prevent population build up, pesticides should be applied within 3 weeks of the first appearance of mites before adults start laying eggs.

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.

31 Agriculture Victoria (2007). Blue oat mite. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite

32 Agriculture Victoria (2007). Blue oat mite. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite

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 & 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.

Culural 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]

MORE INFORMATION

Earth mites (Blue oat and RLEM) – economic considerations

Blue oat mite - cesar

33 Agriculture Victoria (2007). Blue oat mite. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite

7.7 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 Western Australia, Victoria, South Australia and New South Wales. 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.

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 9). 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.

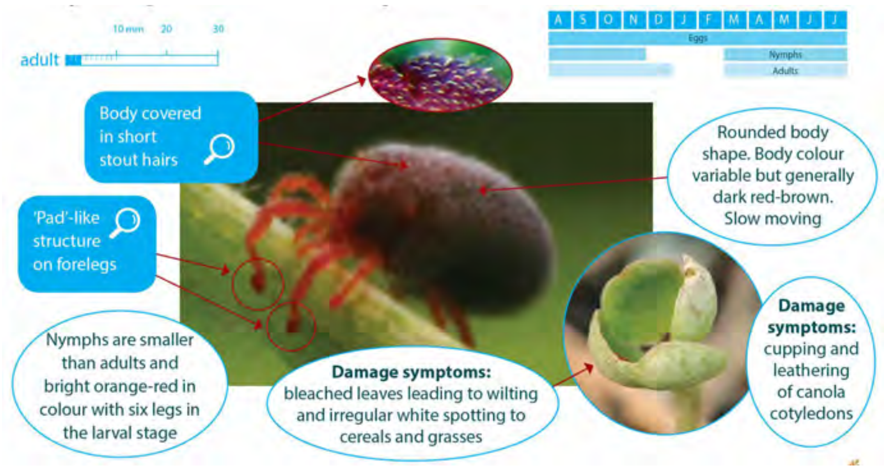


Figure 9: *Adult Balaustium mite.*

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. [34]

7.7.1 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.

34 Grey D, in Agriculture Victoria. (2010). Balaustium mite. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/balaustium-mite

7.7.2 Managing Balaustium mite

Key points:

- Early control of summer and autumn weeds, especially capeweed and grasses will help to control populations.
- Applications of synthetic pyrethroids at the highest registered rate provides control. Organophosphates are not effective against this pest. [35]

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 prove to 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 or canola, a paddock could be sown to a broadleaf plant that *Balaustium* mites have not been reported to attack, such as vetch. [36]

MORE INFORMATION

Mites (bryobia mite and balaustium mite) - economic considerations for management

Balaustium mite – cesar

7.8 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.

35 DAFWA. (2015). Balaustium mite. https://www.agric.wa.gov.au/mycrop/diagnosing-balaustium-mite

36 Grey D, in Agriculture Victoria. (2010). Balaustium mite. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/balaustium-mite

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 Western Australia, Victoria, South Australia, and New South Wales. They have also been recorded in Tasmania and Queensland.

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 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 10).

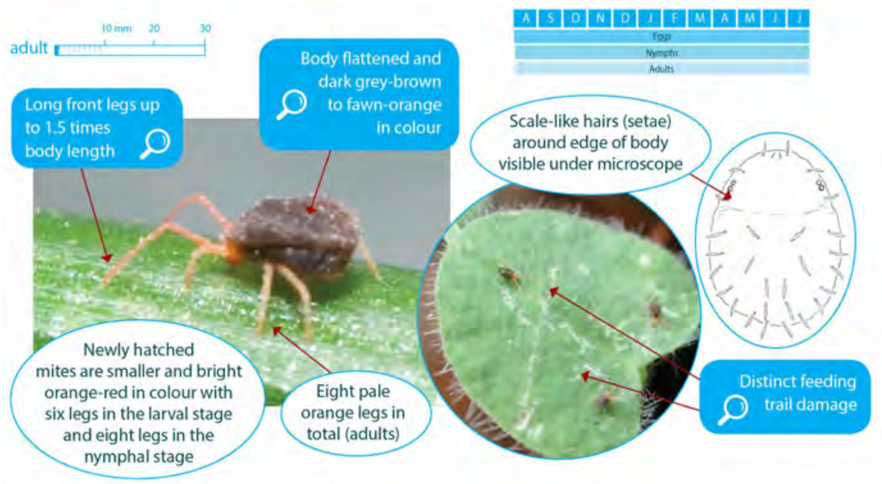


Figure 10: *Distinguishing characteristics of Bryobia mites.*

Source: Bellati et al. 2012 in cesar

7.8.1 Damage cause by mite

Bryobia mites tend to cause most damage in autumn where 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.

7.8.2 Managing Bryobia mites

Key points:

- Bryobia mite is difficult to control if sprays are targeted to stop damage to crops at emergence.
- It is best controlled by killing all weeds well before seeding and/or applying a miticide to the weeds with the knockdown herbicide. [37]

Biological

There are currently no known biological control agents for *Bryobia* mites in Australia.

37 DAFWA.(2015). Diagnosing bryobia mite. https://www.agric.wa.gov.au/mycrop/diagnosing-bryobia-mite

MORE INFORMATION

Mites (bryobia mite and balaustium mite) - economic considerations for management

Bryobia mite - cesar

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. [38]

7.9 Lucerne flea

The lucerne flea, *Sminthurus viridis* (Collembola: *Sminthuridae*), is a springtail that is found in 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, including WA. It is not related to the fleas which attack animals and humans.

High numbers are often found in the winter rainfall areas 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.

Lucerne fleas are mainly a pest of young legume pastures and broadleaf crops but can also affect cereals. They are commonly observed on loam-clay soils.

Lucerne flea is a European insect that is a pest on heavy soils in WA. It requires cool, moist conditions and will produce up to five generations in most years with the final generation of females each season laying eggs that over-summer in the soil. The first soaking autumn rains cause over-summering eggs to hatch. Broadleaf weeds, particularly capeweed, favour lucerne flea.

In the paddock look for small jumping bugs that appear early in the season and chew young leaves on heavier textured soils.

On plants look for chewed leaves with transparent 'windows'. [39]

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 11). 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.

38 Umina P, Hangartner S, McDonald G. (2015). Bryobia mite. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Bryobia-mite

39 DAFWA. (2015). Diagnosing Lucerne flea. https://www.agric.wa.gov.au/mycrop/diagnosing-lucerne-flea

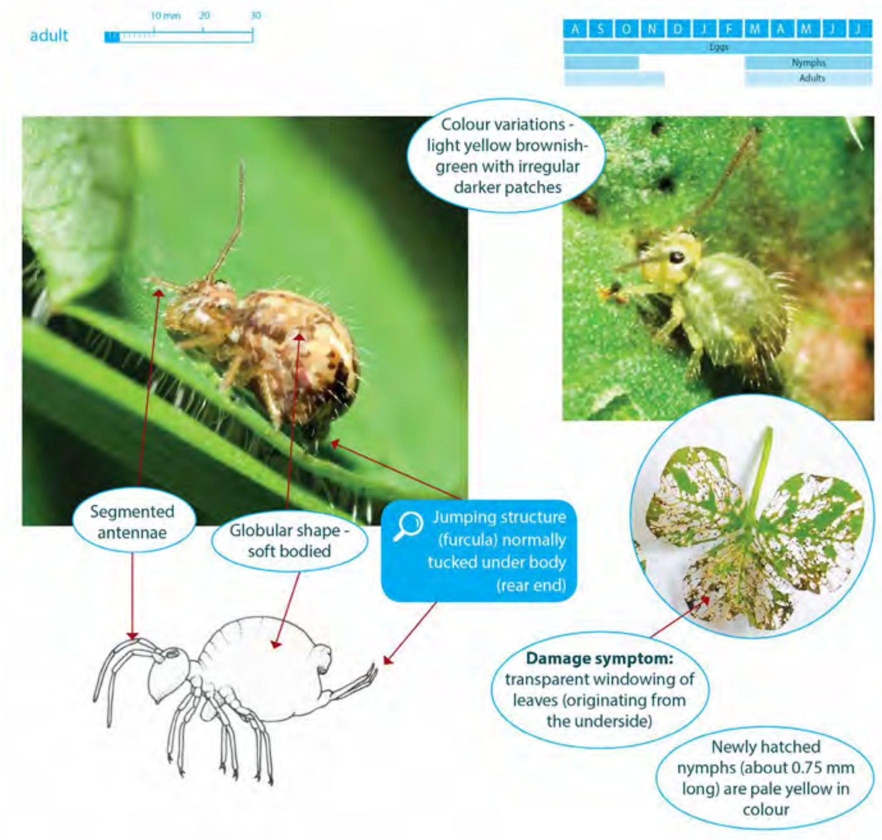


Figure 11: *Distinguishing characteristics of the Lucerne flea.*

Source: Bellati et al, 2012 in cesar

7.9.1 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 which can appear as numerous small 'windows'. In severe infestations this damage can stunt or kill plant seedlings. [40]

7.9.2 Managing Lucerne flea

Key points:

- Apply systemic or contact insecticides.
- Do not use synthetic pyrethroid sprays as these are ineffective against lucerne flea. [41]

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.

40 McDonald G. (2008). Lucerne flea. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/lucerne-flea

41 DAFWA. (2015). Diagnosing Lucerne flea. https://www.agric.wa.gov.au/mycrop/diagnosing-lucerne-flea

It is important to frequently inspect winter crops, particularly canola and pulses, 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 (eg. 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 4). 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 Western Australia but has since been distributed to eastern Australia and there are some examples of this mite successfully reducing lucerne flea numbers. Although rarer, the spiny snout mite can also drastically reduce lucerne flea populations, particularly in autumn.

Photo 4: *Predatory adult snout mite.*

Photo: A. Weeks (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. [42]

MORE INFORMATION

Lucerne flea – economic considerations

Lucerne flea - cesar

7.10 Armyworm

Armyworms are pests of cereal crops and historically have been frequently found along the south coast of Western Australia and occassionally in other wheatbelt localities.

In WA damage to wheat and oat crops from armyworms occurs less frequently and is usually minor compared to damage in barley. Armyworms are seldom a serious problem in pastures.

Armyworm caterpillars vary in colour depending on their species and numbers within crops. They can be distinguished from other caterpillars by their large head and three prominent white stripes on the 'collar' behind the head. They have smooth bodies with a sparse covering of fine hairs. Moths have stout bodies pale to cream in colour with a wing span of 40 millimetres (mm), they fly at night and some armyworm species are strongly attracted to lights.

Occasionally armyworm moths move in large flights in search of food, but usually damaging populations breed within localised areas. On the south coast of Western Australia armyworms have 3–4 generations per year and can survive the summer on self-sown cereals and grasses that germinate with summer rains. During spring it can take as little as three weeks for larvae to reach a damaging size after eggs are laid.

42 McDonald G. (2008). Lucerne flea. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/lucerne-flea

The first visible sign of armyworm caterpillars is often their green to straw-coloured droppings, about the size of a match head, found on the ground between the cereal rows. Damage to weeds, especially their preference for ryegrass, is also a sign of their presence.

In cereal crops isolated patches of the crop can be found with chewed leaves, awns and grains on the seed heads damaged. Caterpillars of various sizes up to 4 cm long may be seen in the crop (Figure 12). They may be on the plant or under leaf litter on the ground. Armyworm can be found during the day on plants but are usually unseen as they prefer to shelter during the day and feed mostly at night. Armyworm caterpillars can often be found hiding under the inter-row leaf litter within patches of crop where damage is seen. Caterpillar droppings resemble small 'green' bales of hay and can often be seen on the ground below the crop canopy. [43]

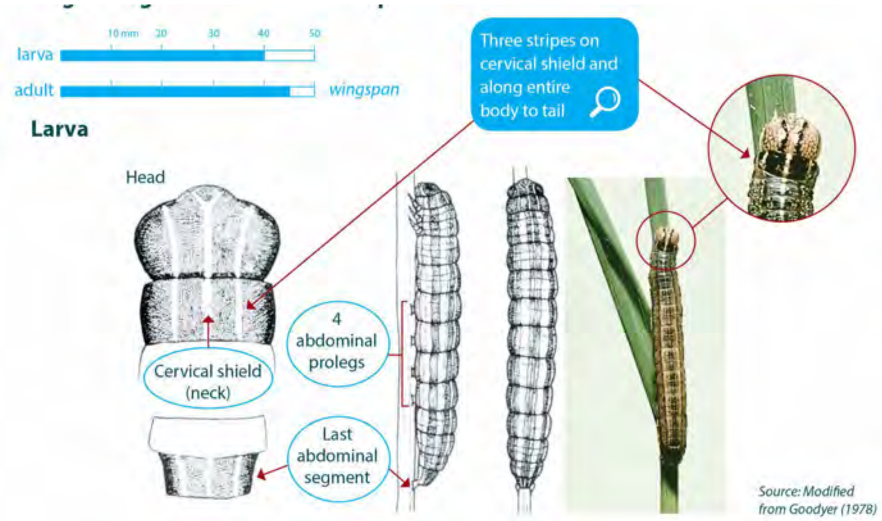


Figure 12: *Distinguishing characteristics of Armyworm larvae.*

Source: cesar

7.10.1 Thresholds for control

The threshold for control in cereals other than barley is much higher than for barley as only grains are consumed and heads are very rarely dropped. Laboratory trials have shown that the yield loss in wheat per hectare per grub per square metre equals 5.4 kilograms per hectare. Given a wheat price of $180 per tonne and the cost of insecticide and its application of $10 per hectare, the threshold number of grubs, above which spraying is warranted on economic grounds, is approximately 10 per square metre. [44]

7.10.2 Managing armyworms

Key points:

- Destroy weedy paddocks several weeks before sowing pasture or crop. This will reduce the feed source for insects.
- Heatwaves may reduce armyworm caterpillar numbers.
- Native parasites can control armyworm biologically so spraying every year is not normally required.
- Spray application to damaging levels of armyworm maybe needed close to crop ripening. Spray withholding periods need to be observed. Increased spray volumes or chemical rates may be required in high-yielding bulky crops.

43 Micic S. (2016). Management of armyworm in cereal crops. DAFWA. https://www.agric.wa.gov.au/grains/management-armyworm-cereal-crops?page=0%2C0

44 Micic S. (2016). Management of armyworm in cereal crops. DAFWA. https://www.agric.wa.gov.au/grains/management-armyworm-cereal-crops?page=0%2C0

Armyworm are easily controlled by insecticides, especially if detected early and sprays are applied when economic damage is imminent.

On the south coast spraying is unnecessary in most years, as natural events can control the pest or allow the crop to mature without damage. The presence of large larvae in spring should not prompt treatment automatically.

The most serious situation is the presence of many large caterpillars coinciding with the maturing of the crop. Usually, little damage occurs in the leafy stages, but it is advisable to check crops regularly after the flag leaf appears.

Weather is the most important factor determining the size and stage of the pest population. Outbreaks appear in spring, following successful preceding generations. The weather is also important when the crop is maturing, as an extended ripening allows the pest more time to develop and damage the crop.

Biological control agents can be important in some years. These include parasitic flies and wasps, predatory beetles and diseases.

Chemical control may finally be necessary as the crop begins to ripen. A number of effective synthetic pyrethroid insecticides are registered for the control of armyworm. However, their effectiveness is often dependent on good penetration into the crop. This can sometimes be difficult to achieve in high-yielding thick canopy crops, especially when caterpillars are resting under leaf litter at the base of plants.

Monitor after spraying

Crops should be check after spraying to ensure that the application is effective. Consideration of insecticide withholding periods is important in late sprayed crops.

Monitoring

Assessing the numbers of armyworm in a cereal crop can be difficult, as their movements will vary with weather conditions and feeding preference. Sometimes they are found sheltering on the ground and under leaf litter, whilst on other days they will be high up on the plants or on the heads and easily picked up using sweepnets.

If ryegrass is present in the crop, they often prefer to feed on that, until it runs out.

Armyworm caterpillars may be confined to only small portions of a crop. Several different locations within the crop should be checked for caterpillar numbers before deciding on control measures.

A suggested monitoring procedure is:

- Look for signs of caterpillar droppings and damaged ryegrass heads (if present).
- Look for damage to the foliage of the crop.
- Look for caterpillars on the plants and on the ground after shaking the plants and searching the leaf litter between rows.

If you can't find caterpillars in spring, it can be two or three weeks before a population of damaging-sized caterpillars could develop, so check again in at least two weeks' time. [45]

7.11 Slugs and snails

Numbers of slugs and snails (Table 3) have increased in broadacre cropping in Western Australia with the use of minimum tillage and stubble-retention practices. These systems increase the organic content of paddocks and the soil moisture content leading to higher survival levels of slugs and snails.

Slugs are pests of crops, especially in the higher rainfall regions of Western Australia. Slugs tend to be restricted to soils with a clay content.

MORE INFORMATION

[Snail Identification and control: The Back Pocket Guide]

[Slugs in Crops: The Back Pocket Guide]

45 Micic S. (2016). Management of armyworm in cereal crops. DAFWA. https://www.agric.wa.gov.au/grains/management-armyworm-cereal-crops?page=0%2C0

Snails are found on all soil types. White Italian and vineyard snails prefer alkaline sandy soils; the small pointed snail is able to survive on all soil types even acidic soils. Liming areas where there are snails will aid snail survival.

The small pointed snails however, are only known to cause economic crop damage in high rainfall areas. Whereas the vineyard and white Italian snails are known to cause crop damage in the Greenough flats (which is the region between Dongara and Geraldton) and the Geraldton region. [46]

Table 3: *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 is greater than 25%	Resident pest Surface active, but seeks moist refuge in soil macropores
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 or maize crops fail to emerge Prefers sandy soil in high-rainfall areas (>550 mm), and heavier soils in low-rainfall areas (<500 mm) Surface active (feeding), but seeks moist refuge in soil macropores

46 Micic S. (2016). Identification and control of pest slugs and snails for broadacre crops in Western Australia. DAFWA. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Brown field slug *Deroceras invadens* or *D. laeve*  Photo: Michael Nash, SARDI	Usually brown all over with no distinct markings 25–35 mm long 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
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 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 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 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.

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
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
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 Like 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

7.11.1 Damage caused by slugs and snails

Slug and snail pests damage plant seeds (mainly legumes), recently germinated seeds, seedlings and leaves and can be a contaminant of grain at harvest.

Snails are not known to damage seeds, but may damage germinated seeds close to the soil surface. However, slugs, especially black keeled slugs, will feed in the furrows on seeds of legumes. These slugs are not known to feed on ungerminated canola or cereal seeds.

Irregular pieces chewed from leaves and shredded leaf edges are typical of snail and slug presence. Damage to canola and legume crops can be difficult to detect if seedlings are chewed down to the ground during emergence.

Cereal crops are likely to survive damage by slugs and snails, while canola and lupins cannot compensate for the damage or loss of cotyledons. If cereals are deep sown into a fine, firm seedbed, the slugs and snails are not able to feed on the growing point and emerging crops may recover from damage after treatment.

Different species of slugs cause differing amounts of damage. Cereals are less likely to sustain damage from reticulated slugs, than from black keeled slugs. Canola crops need careful monitoring to assess plant losses. [47]

47 Micic S. (2016). Identification and control of pest slugs and snails for broadacre crops in Western Australia. DAFWA. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

7.11.2 Thresholds for control

Table 4: *Suggested thresholds for control of slugs and snails in broadacre crops.*

Species	Oilseeds	Cereals	Pulses	Pastures
Black keeled slug	1–2/m^2	1–2/m^2	1–2/m^2	5/m^2
Reticulated slug	1–2/m^2	5/m^2	1–2/m^2	5/m^2
Small pointed snail	20/m^2	40/m^2	5 per seedling	100/m^2
Vineyard snail	5/m^2	20/m^2	5/m^2	80/m^2
White Italian snail	5/m^2	20/m^2	5/m^2	80/m^2

Please note: the above thresholds are from limited data. It is essential to carefully monitor crops as distributions of snails and slugs are patchy.

Source: DAFWA

7.11.3 Management of slugs and snails

From a management point of view, slugs and snails have similar lifecycles. This means similar management techniques can be employed to control them in broadacre crops. Effective management requires applying controls that coincide with different phases of the pest's lifecycle (Figure 13).

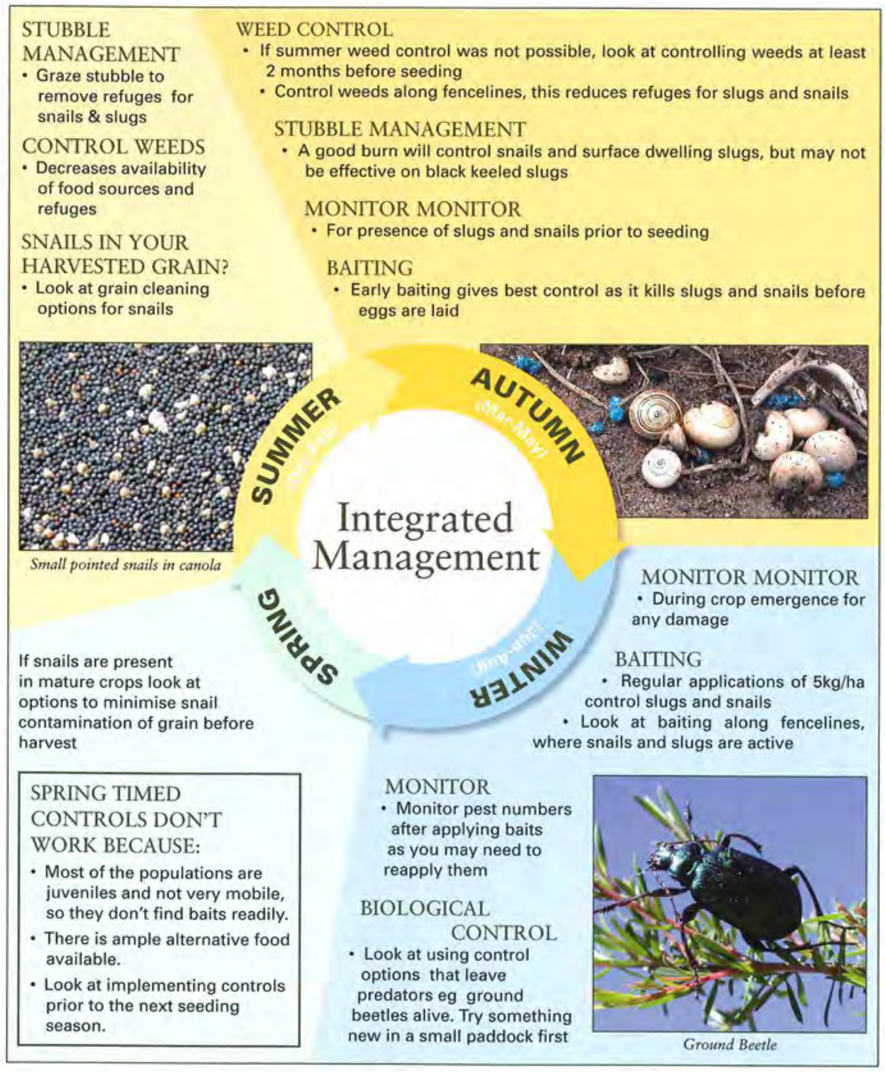


Figure 13: *Integrated control options that align with slug and snail lifecycles, breaking the cycle of reinfestation.*

Source: DAFWA

Chemical control

There are no sprays registered for snail and slug control in broadacre cropping. Be aware that insecticides commonly used to control insect pests of broadacre crops are not effective against slugs and snails.

Baits

Slugs and snails can only be controlled by baits if they are mobile and looking for food. Note that young snails ie those less than 7 mm in diameter for round snails and 7 mm in height for conical snails are not likely to be controlled by baits. Young snails feed on decaying plant matter and are not likely to be attracted to baits.

Snail and slug numbers should be monitored to determine if there is a need to bait especially during crop emergence. Baiting will generally only kill 50% of a slug population at any one time and then mainly the larger ones. Younger slugs may emerge in successive waves. Monitoring numbers (refer to Table 1) will determine if there is a need for multiple bait applications. Based on this, baiting can be confined to areas of high snail/slug density.

All baiting must be stopped at least two months prior to harvest to ensure baits are broken down and do not become a contaminant of grain.

MORE INFORMATION

Snails: Bash'em Burn'em Bait'em

Biological control

There are a range of native ground beetles (family Carabidae: carabids) that are generalist predators, which attack slugs. These beetles would normally eat other prey, but some have been found to have a significant impact on slug populations. They can be important factor in controlling slugs, in combination with baiting.

The only biological control developed for snails (by the South Australian Research and Development Institute) is a parasitic fly, *Sarcophaga penicillata.* Its effectiveness has been limited.

Cultural control

Burning

Burning prior to seeding, is one of the most effective methods for pre-breeding snail control and provides some slug control. The burning itself kills snails but does not kill slugs. The lack of food and shelter following a burn makes it more likely that slugs will move elsewhere.

Before deciding to burn, soil type and weather conditions need to be taken into consideration. Also, summer weeds should be desiccated and browned off. Rocks also provide hiding places and these, if possible, should be turned by cabling or fire harrowing just prior to burning.

It is important to ensure that an even burn is applied across the paddock, as unburnt patches will provide habitats (refuges) especially for snails. An even burn causes 80–100% kill, patchy burn 50–80% kill. Burning on a warm day with little wind in a paddock that has a reasonable fuel load should achieve good control, can be less effective on small pointed snails if rocks are not turned.

When snail populations are large, a strategic burn every three or four years will assist in controlling snail numbers.

Grazing

Grazing animals will knock snails from stubble and may also trample them. Grazing will also decrease the stubble load into a paddock about to be seeded. Decreasing stubble ground cover will decrease refuges for slugs and snails.

Tillage

The most effective form of tillage to reduce numbers of snails and slugs is wide points or full-cut discs that are used in conventional tillage methods. Ploughing the soil to a depth of 5 cm or more will bury surface snails and slugs. Burying snails, especially small pointed snails, can reduce surface numbers of snails by around 40–60%.

Conventional tillage may have limited impact on black keeled slugs. Tillage will disrupt burrows made by these slugs and may cause some mortality. However, it is unlikely that tillage alone will decrease the number of black keeled slugs sufficiently to protect crops.

If tillage coincides with egg laying by slugs and snails, it may expose buried eggs to the environment. This may cause eggs to dry out and die, thereby decreasing slug and snail populations.

Cultivation of the soil does bury surface trash, disturbing potential shelters for slugs and snails. Ploughing trash residues after harvest has been found to remove over-summering habitat for slugs and snails. [48]

48 Micic S. (2016). Identification and control of pest slugs and snails for broadacre crops in Western Australia. DAFWA. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

7.11.4 Monitoring

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

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

It is a good idea to monitor in:

- January/February to assess stubble management options for slug and snail management
- March/April to assess options for burning and/or baiting
- May to August to assess options for baiting especially along fencelines
- For snails 3–4 weeks before harvest to assess risk of snail contamination of grain and if required, implement options to minimise the risk.

How to find slugs

A useful method to detect areas infested with slugs, prior to seeding or crop emergence, is to lay lines of slug pellets with a rabbit baiter. In infested areas, slugs are attracted to the freshly turned soil and pellets placed in the furrow. Very large numbers can be found dead or dying in the furrows or nearby. On sloping ground, furrows should be run along contours to reduce the risk of soil erosion in the event of heavy rain.

An alternative method to gain an indication of the numbers of slugs present in a paddock is to place wet carpet squares, hessian sacks or tiles on the soil surface. They should at least be 32x32 cm (10% of a square metre). Place pellets under them. After a few days, count the number of slugs under and around each square. Multiplying by 10 will give an estimate of slugs per square metre (/m^2), at least 1–2 slugs/m^2 will cause damage to canola. The table below gives an indication of thresholds.

How to find snails

Snails are usually found on stumps, fencelines and under stubbles. A good way to determine snail numbers on open ground is to use a 32x32 cm square quadrant and count all of the live snails in it. This is an area of 10% of a square metre so multiplying by 10 will give an estimate of snails/m^2. [49]

MORE INFORMATION

[Snails – economic considerations for management]

[Slugs – economic considerations]

49 Micic S. (2016). Identification and control of pest slugs and snails for broadacre crops in Western Australia. DAFWA. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

Nematode management

Key messages

- Triticale is highly resistant to *P. neglectus,* [1] and resistant to *P. thornei*. [2]
- Triticale is thought to be resistant to Cereal cyst nematode (CCN) [3] likely owing to its parent crop, cereal rye. [4]
- Triticale can reduce soil nematodes such as *Pratylenchus neglectus* and *thornei* (root lesion nematodes) and *Heterodera avenae* (cereal cyst nematode). [5]
- Yield losses can be reduced by rotation with resistant and tolerant crops and varieties, good nutrition and sowing early. Variety choice is critical in managing nematode populations in the soil.
- Soil testing is the best way to diagnose nematodes infestations in paddocks and will subsequently inform management decisions.

Many growers use triticale as a disease break in their rotations and value the benefits of triticale for its contribution to soil conservation (Table 1). Triticale assists in maintaining soil health by the reduction of nematodes, such as root-lesion nematodes and cereal cyst nematode. [6]

Table 1: *Triticale variety resistance ratings to nematodes.*

Variety	CCN resistance	*P. neglectus* resistance	*P. thornei* resistance
Astute⚶	R	RMR	MS
Berkshire⚶	-	MR	MS
Bison⚶	R	MR	RMR
Canobolas⚶	-	MR	MSS
Chopper⚶	R	MRMS	MSS
Endeavour⚶	-	MR	SVS
Fusion⚶	R	RMR	MS
Goanna	R	MRMS	SVS
KM10	-	MR	MSp
Rufus	R	MSS	MSS
Tahara	R	MR	S
Tobruk⚶	-	MR	SVS
Tuckerbox	-	MRMS	S
Yowie	R	MR	MSS

Maturity: E = early, M = mid season, L = late, VL = very late Height: M = medium, T = tall Colour: W = white, Br = brown Disease resistance order from best to worst: R > RMR > MR > MRMS > MS > MSS > S > SVS > VS. p = provisional ratings - treat with caution. R = resistant, M = moderately, S = susceptible , V = very. # Varieties marked may be more susceptible if alternative strains are present.

Source: Agriculture Victoria

Successful management of cereal diseases and nematodes relies on:

- farm hygiene to keep fields free of root-lesion nematode (RLN).

1 Williams M. (2013). Root out nematodes and get them tested. https://grdc.com.au/Media-Centre/Media-News/West/2013/10/Root-out-nematodes-and-get-them-tested

2 Soilquality.org. (2016). Root lesion nematode. http://soilquality.org.au/factsheets/root-lesion-nematode

3 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

4 Asiedu, R., Fisher, J. M., & Driscoll, C. J. (1990). Resistance to Heterodera avenue in the rye genome of triticale. *Theoretical and applied genetics*, *79*(3), 331–336.

5 Cooper KV, Jessop RS, Darvey NL in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.http://www.fao.org/docrep/009/y5553e/y5553e00.htm

6 Cooper KV, Jessop RS, Darvey NL in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org. http://www.fao.org/docrep/009/y5553e/y5553e00.htm

- growing tolerant varieties when root-lesion nematodes are present, to maximise yields.
- rotating with resistant crops to keep root-lesion nematodes at low levels.

Test soil to monitor population changes in rotations and to determine RLN species and population density.

- Avoid consecutive susceptible crops in rotations to limit the build-up of RLN populations.
- Choose rotation crops with high resistance ratings, so that fewer nematodes remain in the soil to infect subsequent crops.

8.1 Root-lesion nematode (RLN)

Key points:

- In WA, at least 65% of cropping paddocks (or around 5.7 million hectares) are infested with one or more of the *Pratylenchus* species.
- There are four damaging nematodes present in Western Australia; *Pratylenchus neglectus, P. thornei, P. penetrans,* and *P. quasitereoides* (formerly *P. teres*).
- Root-lesion nematodes cost Australian growers in excess of $250 million/annum.
- Root lesion nematodes reduce development of lateral roots, which decreases the ability of plants to extract water and nutrients.
- Currently, there are no practices that can be applied after a crop is sown, so RLN management is based on:
  - » Rotation with a resistant break crop or pasture to inhibit or reduce nematode reproduction.
  - » In the cropping year, use varieties which are tolerant to the RLN species in your paddock as these suffer little or no yield loss when low or moderate populations of RLN are present in the soil. However, tolerant varieties may still increase RLN numbers. [7]

Pratylenchus spp. are microscopic worm-like organisms less than one-millimetre in length which feed on root tissues. *P. neglectus* is the dominant RLN species in all of Australia's cropping regions. *P. neglectus* has a wide host range, infecting all cereals as well as crops grown in rotation with cereals (grain legumes, pasture legumes and oilseeds). However, nematode multiplication differs both between and within host species. Damage caused by *P. neglectus* impairs root function, limiting water and nutrient uptake, leading to poor growth and yield decline.

Glasshouse trials have been conducted to compare nematode multiplication on roots of triticale, wheat and rye varieties. Roots of triticale were found to contain fewer nematodes than the other cereals. Triticale is thus a useful rotational crop for areas infested with the root lesion nematode. [8]

Triticale is thought to be susceptible to *P. penetrans*, however, this information is based on preliminary trials and from observations of samples submitted to AGWEST Plant laboratories. More research is needed. [9]

Root lesion nematodes emerged as potential problems in cereals (and other crops) after management strategies were implemented to control cereal cyst nematode and take-all. Yield losses are variable, but present estimates for intolerant varieties indicate a 1% yield loss per 2 nematodes per gram soil. *Pratylenchus thornei* (Photo 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.

Root lesion nematodes survive summer as dormant individuals in dry soil and roots, and become active after rain. They can survive several wetting/drying cycles. About

7 Collins S, Wilkinson C, Kelly S, Hunter H, DeBrincat L. (2014). Root lesion nematode has a picnic in 2013. DAFWA.

8 Vanstone, V., Farsi, M., Rathjen, T., & Cooper, K. (1996). Resistance of triticale to root lesion nematode in South Australia. In *Triticale: Today and Tomorrow* (pp. 557–560). Springer Netherlands.

9 Soilquality.org. (2016). Root lesion nematode. http://soilquality.org.au/factsheets/root-lesion-nematode

three generations of the nematodes are produced each season, with the highest multiplication in spring. [10]

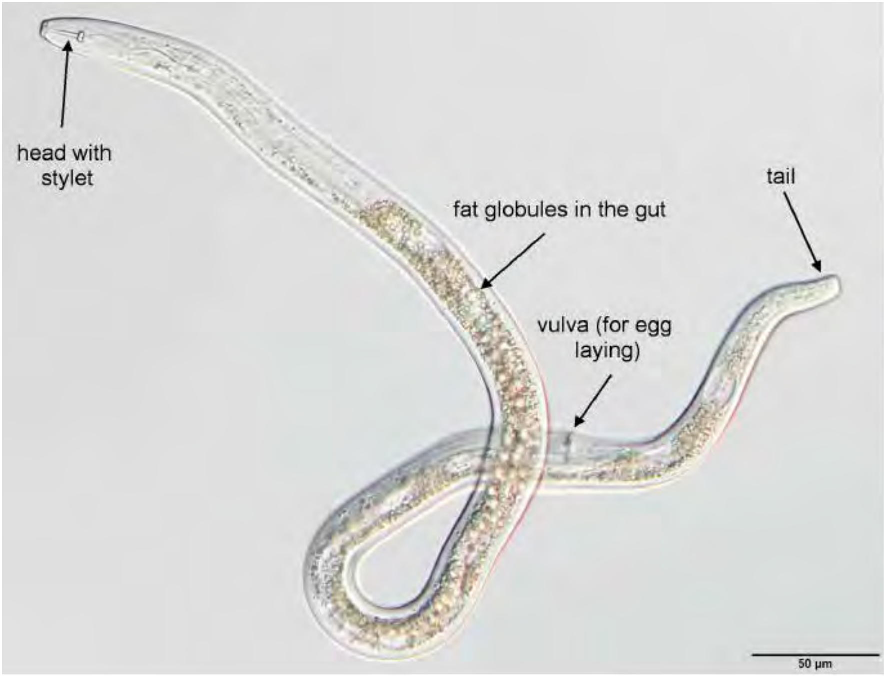


Photo 1: *A Pratylenchus thornei adult female viewed under the microscope. The nematode is approximately 0.65 mm long.*

Source: GRDC

In WA, at least 65% of cropping paddocks (or around 5.7 million hectares) are infested with one or more of the *Pratylenchus* species. In about 40% of cases the nematode is at levels capable of causing crop damage and yield loss of 5–15%. *P. neglectus, P. thornei, P. quasitereoides* and *P. penetrans* have been identified in WA and research is underway to learn more about these species and the rotations that will limit their populations in cropping soils. Forty per cent of RLN identified in WA is *P. neglectus*; 10% *P. quasitereoides* and 10% mixed species. *P. penetrans* is rare in WA but can cause severe damage to some crops. More than one RLN species can be found in the roots of an individual crop, although one species usually dominates. [11]

The extent of RLN occurrence across Australia has recently been estimated (Figure 1).

10 McKay A. (2016). Root lesion nematode – South Australia. http://www.soilquality.org.au/factsheets/root-lesion-nematode-south-australia

11 GRDC. (2009). Plant parasitic nematodes Fact sheet – Southern and western region. Managing cereal cyst and root lesion nematodes.

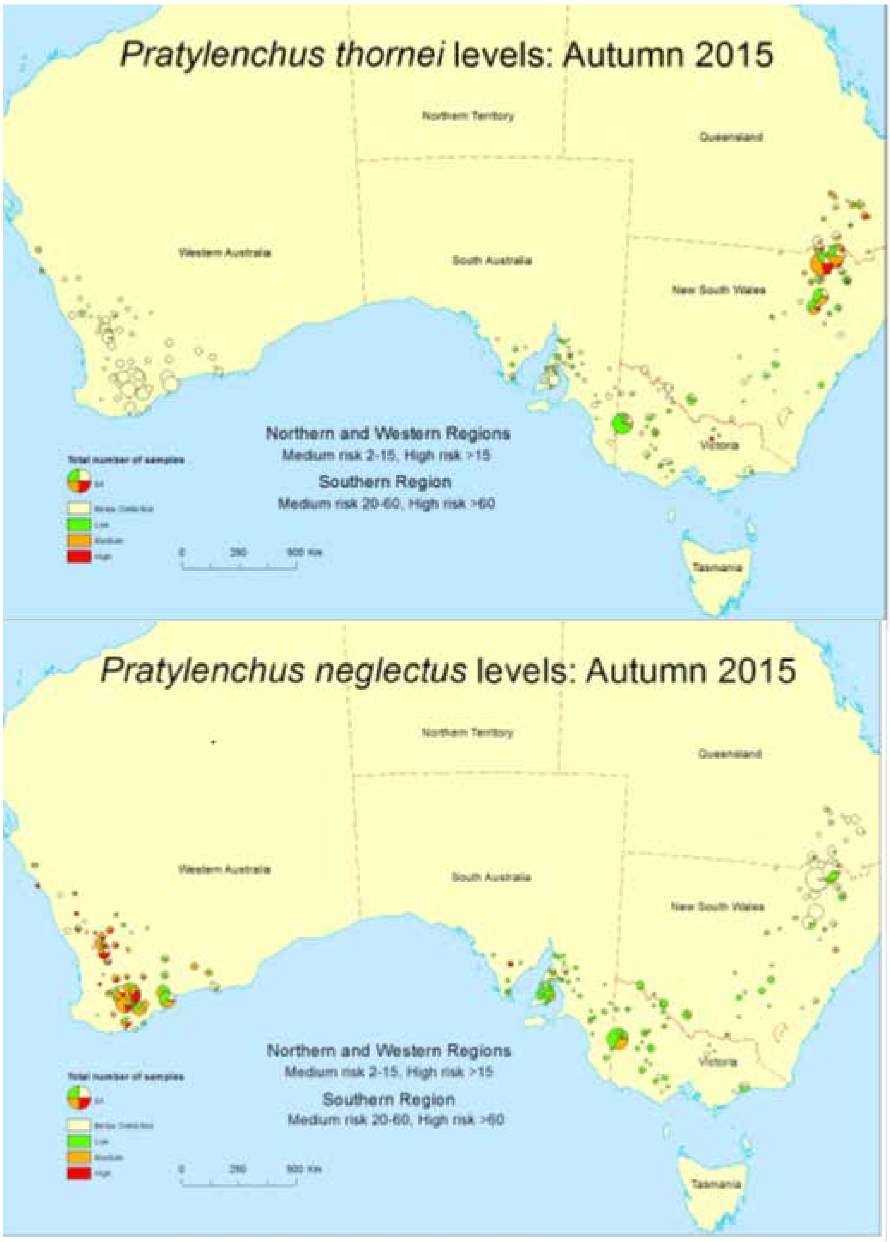


Figure 1: *The distribution and risk of causing yield loss of samples submitted to PreDictaB, SARDI in autumn 2015 for (top)* Pratylenchus thornei *and (bottom)* P. neglectus*.*

Maps are reproduced with permission from SARDI, Source: GRDC

IN FOCUS

Root lesion nematodes in WA

Key points:

- In 2013 RLN species were found in 90% of 130 paddocks surveyed in WA and RLN levels were high enough to cause between 15 and 50% yield loss in 48% of the paddocks assessed.
- This level of infestation may have been caused by a green bridge of volunteer crop species in some areas. Pasture and weeds after March rains may have allowed RLN numbers to increase before crops were sown. Plant stress from the prolonged dry spell in early winter may also have left crops more susceptible to RLN infestation.

RLN levels in a range of crops growing from Northampton in the north to Albany and Esperance in the south were assessed in 2013 at DAFWA trial sites. Data was also collected from Focus Paddocks (50 samples assessed by DAFWA, Nematology) and from samples sent to AGWEST Plant Laboratories. This data was summarised to determine the proportion of paddocks containing plant parasitic nematode species and the severity of infestations. In 2012, a trial site for *Pratylenchus quasitereoides* was identified in Esperance in response to grower observations of yellowing and poor growth in a 40 ha paddock of wheat. The paddock held high levels of *P. quasitereoides* (11,000/g root) which caused approximately 46% yield loss. The trial area was planted in 2013 with canola (cv. Cobbler) to increase *P. quasitereoides* and lupins (cv. Jennabillup) to decrease *P.quasitereoides* populations. The remainder of the paddock was sown with a soft seeded serradella (cv. Cadiz) known to be moderately resistant to *P. neglectus*. At the end of the cropping season, trial plots were sampled to determine if nematode levels had been successfully manipulated.

Results

RLN was identified across all cropping zones in 2013 (Figure 2). RLN species were found in 90% of the 130 paddocks surveyed. *Pratylenchus neglectus* and *P. quasitereoides* were the most common species in 68% and 24% of paddocks, respectively (Table 2). Two or three RLN species were found together in 18% of paddocks, with the most common combination being *P. neglectus* and *P. quasitereoides* (13%). RLN was not detected in 10% of paddocks. Of those infested with RLN, 48% had population densities with the potential to cause yield losses of between 15–50% in wheat. In 18% of paddocks, growers may not have seen visual effects in the crop, but RLN populations densities were sufficient to cause yield losses of up to 15%. Only 24% of the 130 paddocks tested contained a low level of RLN, which would not impact yield but could increase to damaging levels in susceptible cropping sequences.

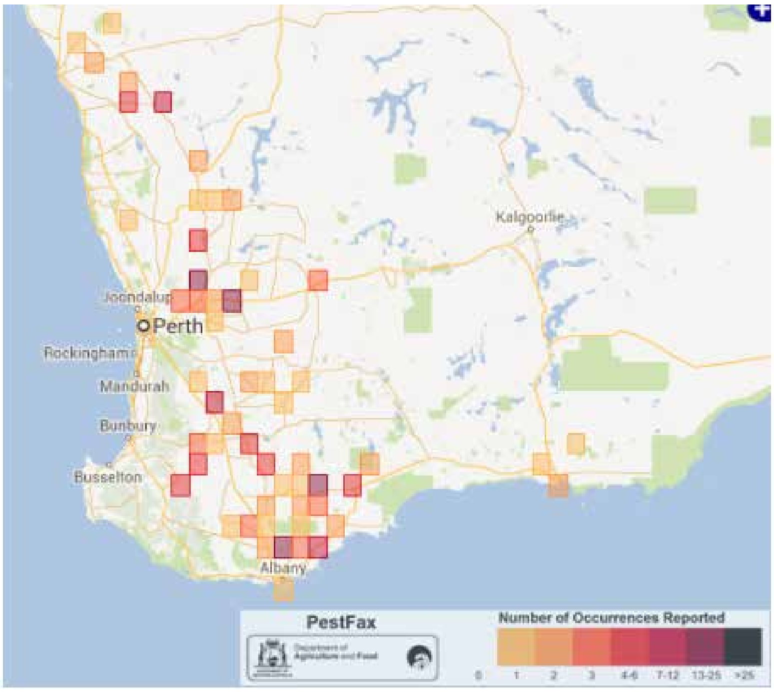


Figure 2: *Occurrence of root lesion nematodes in paddocks surveyed during 2013 in WA. Map adapted from Pestfax Database DAFWA.*

Source: DAFWA

Table 2: *Severity of infestation, total number of paddocks infested and number of paddocks infested with each Pratylenchus species in each severity category from samples taken across broadacre cropping zones of WA in 2013 (April-October, n = 130).*

Source: DAFWA

Severity of Infestation[1]	Total paddocks	P. neglectus[2]	P. quasitereoides	P. thornei	P. penetrans	spp.[3]	NO RLN
0	13 (10%)						13
1	31 (24%)	19	7	0	0	11	
2	24 (18%)	26	8	2	0	0	
3	53 (41%)	37	14	6	2	0	
4	9 (7%)	7	2	0	0	0	
Total with RLN	117 (90%)	89 (68%)	31 (24%)	8 (6%)	2 (2%)	11 (8%)	

1 Severity ratings; 0 = nil, 1 = < 0.2 /mL soil or 0- 200 /g dry root, 2 = 0.2–1 /mL soil or 200–1000 /g dry root, 3 = 1–10 /mL soil or 1000 - 10 000 /g dry root, 4 = > 10 /mL soil or > 10 000 /g dry root.
2 Number does not sum to total number of paddocks sampled as some paddocks contained more than one RLN species.
3 No adult Pratylenchus in sample, therefore species could not be confirmed.

MORE INFORMATION

Tips and tactics: Root-lesion nematodes Western region.

Plant parasitic nematodes factsheet

A number of paddocks visited in 2013 for diagnostic assessment had both Rhizoctonia and RLN. These are commonly found together in WA and in combination may be synergistic in causing yield losses. [12]

Researcher's tip

12 Collins S, Wilkinson C, Kelly S, Hunter H, DeBrincat L. (2014). Root lesion nematode has a picnic in 2013. DAFWA.

VIDEOS

WATCH: Root lesion nematode has a picnic 2013, WA – Sarah Collins.

WATCH: GCTV6: Root-lesion nematodes.

WATCH: Understanding root-lesion nematodes.

8.1.1 Symptoms

Paddock

- Crops appear patchy with uneven growth, and may appear nutrient deficient (Photo 2).
- Double sown and more fertile areas are often less affected.
- There may be stunted growth and waviness across the paddock.

Photo 2: *Poor vigour cereal in high RLN plot (left) compared to healthy plot with low RLN (right).*

Photo: Grant Hollaway) Source: Soilquality.org

Plant

- Affected plants stunted and poorly tillered and can wilt despite moist soil.
- Roots can have indistinct brown lesions or, more often, generalised root browning (Photo 3).
- Badly affected roots are thin and poorly branched with fewer and shorter laterals.
- Roots may appear withered with crown roots often less affected than primary roots.
- Roots can assume a 'noodle-like' root thickening appearance. [13]
- Unlike the cereal cyst nematode, root lesion nematodes do not cause the roots to swell or knot and no cysts are produced. [14]

13 DAFWA. (2016). Diagnosing Root lesion nematode in cereals. https://www.agric.wa.gov.au/mycrop/diagnosing-root-lesion-nematode-cereals

14 CropPro. (2014). Root lesion nematode (RLN). http://www.croppro.com.au/crop_disease_manual/ch03s07.php

VIDEOS

WATCH: How to diagnose root-lesion nematode.

WATCH: Root-Lesion Nematodes. Resistant cereal varieties have surprising impacts on RLN numbers.

MORE INFORMATION

Diagnosing root lesion nematode in cereals

GRDC Update Paper: Root-lesion nematodes; importance, impact and management.

Photo 3: *Discolouration and lack of lateral roots on cereals is caused by root lesion nematodes.*

Photo: Frank Henry. Source: Soilquality.org

8.1.2 Varietal resistance

Triticale is highly resistant to *P. neglectus,* [15] resistant to *P. thornei*. [16]

Triticale is thought to be susceptible to *P. penetrans*, however, this information is based on preliminary trials and from observations of samples submitted to AGWEST Plant laboratories. More research is needed. [17]

See Table 1 for Triticale variety resistance ratings to nematodes, where known.

Limited information is available on the resistance of crops to *P. quasitereoides.* However, lupins are generally resistant, whilst cereals and canola are generally susceptible. Crops that are resistant to *P. penetrans* are often highly susceptible to *P. neglectus* or *P.quasitereoides* highlighting the importance of knowing which species of RLN is present, as management of one RLN species may be causing an increase in another. [18]

15 Williams M. (2013). Root out nematodes and get them tested. https://grdc.com.au/Media-Centre/Media-News/West/2013/10/Root-out-nematodes-and-get-them-tested

16 Soilquality.org. (2016). Root lesion nematode. http://soilquality.org.au/factsheets/root-lesion-nematode

17 Soilquality.org. (2016). Root lesion nematode. http://soilquality.org.au/factsheets/root-lesion-nematode

18 Collins S, Wilkinson C, Kelly S, Hunter H, DeBrincat L. (2014). Root lesion nematode has a picnic in 2013. DAFWA.

8.1.3 Thresholds for control

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. [19]

8.1.4 Conditions favouring development

Nematodes can spread through a district in surface water (e.g. floodwater) and can be moved from one area to another in soil adhering to vehicles and machinery. They have the ability to quickly build up populations in the roots of susceptible crops and remain in the soil during fallow. As a result the yield of subsequent crops can be significantly reduced.

8.1.5 Management of RLN

Key points:

- 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
- To manage RLN populations, it is important to increase the frequency of RLN resistant crops in the rotation
- Multiple resistant crops in a rotation will be necessary for long term management of RLN populations
- There are consistent varietal differences in *Pt* resistance within wheat and chickpea varieties
- Avoid crops or varieties that allow the build-up of large populations of RLN in infected paddocks
- Monitor the impact of your rotation

There are four key strategies in reducing the risk of root lesion nematodes:

1. Have soil tested for nematodes in a laboratory (Figure 3).
2. Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.
3. Choose tolerant varieties to maximise yields (go to nvtonline.com.au). Tolerant varieties grow and yield well when RLN are present.
4. Rotate with resistant crops to prevent increases in root-lesion nematodes. When high populations of RLN are detected you may need to grow at least two resistant crops consecutively to decrease populations. In addition, ensure that fertiliser is applied at the recommended rate to ensure that the yield potential of tolerant varieties is achieved.

19 GRDC. (2015). Tips and tactics: Root lesion nematodes Western region. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/tt-rootlesionnematodes

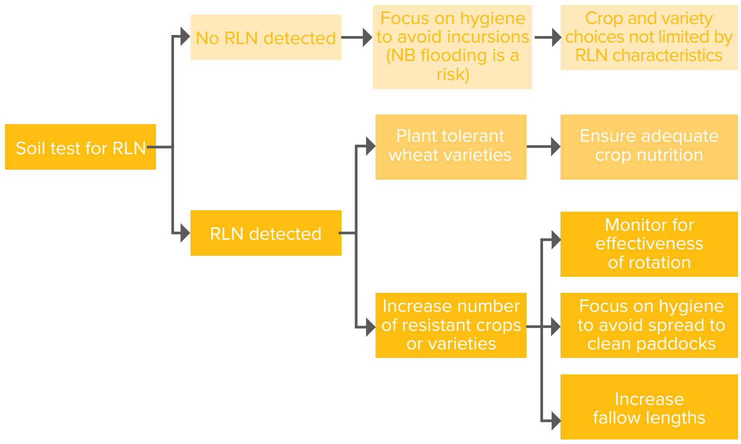


Figure 3: *RLN management flow chart - A simplified chart that highlights the critical first step in the management of RLN is to* **test your soil and determine whether or not you have an issue to manage**. *NB where RLN are present, growers should focus on both 1) planting tolerant wheat varieties and 2) increasing the number of resistant crops/varieties in the rotation.*

Source: GRDC

There are four major control strategies against RLN:

5. **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.
6. **Variety choice and crop rotation:** *These are currently our most effective management tools for RLN.* However the focus is on two different characteristics - *Tolerance* (ability of the variety to yield under RLN pressure) and *Resistance* (impact of the variety on the build-up of RLN populations). NB varieties and crops often have varied tolerance and resistance levels to various *Pratylenchus* spp.
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 (VAM) levels and create more cropping issues than they solve.
8. **Nematicides** (control in a drum): 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. [20]

Soil testing

Make use of available testing services to determine nematode species and levels, but be aware that PreDicta-B™ cannot currently detect *P. quasitereoides* in WA crops. Paddocks can be sampled at the end of the season to determine if RLN populations have been sufficiently reduced. AGWEST Plant Laboratories can conduct in-season nematode diagnoses. [21]

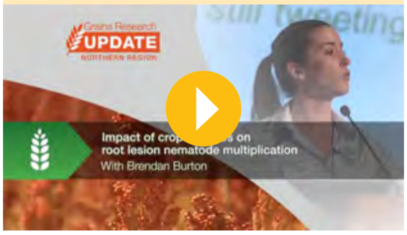
PreDictaB

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

VIDEOS

WATCH: Root lesion nematodes – What can I do?

WATCH: Crop variety effect on nematode.



20 Burton B, Norton R, Daniel R. NGA. (2015). GRDC Update Paper: Root-lesion nematode; importance, impact and management. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

21 Collins S, Wilkinson C, Kelly S, Hunter H, DeBrincat L. (2014). Root lesion nematode has a picnic in 2013. DAFWA.

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 4).

Photo 4: *Sampling for PreDicta B*

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

Growers can access PreDicta B diagnostic testing services through a SARDI accredited agronomist. They will interpret the results and give advice on management options to reduce the risk of yield loss.

SARDI processes PreDicta B samples weekly between February to mid-May (prior to crops being sown) every year.

These timeframes help assist growers with their cropping programs.

PreDicta B is not intended for in-crop diagnosis. See the crop diagnostic webpage for other services.

DDLS – plant pathology services

DDLS - Plant pathology (formerly part of AGWEST Plant Laboratories) is a service area under the DAFWA Diagnostic Laboratory Services (DDLS) and an amalgamation of DAFWA plant and animal laboratory and inspection services.

DDLS provide critical disease diagnostics services for broadacre crops (cereals, canola and pulses), pastures and horticulture (ornamentals, nursery plants, amenity horticulture, turf, soil, fruits and vegetables).

Provides:

- routine plant disease diagnosis in plants, potting mix, soil and water
- nematode analysis of roots and soils for horticulture and broadacre crops
- plant virus identification
- specific disease testing for seed crops to meet export requirements
- plant pathogen testing to fulfil nursery accreditation and export requirements.

After diagnosis, DDLS can direct you to specialists to:

- Implement best practice pest and disease control.
- Reduce your use of incorrect or unnecessary chemicals.

MORE INFORMATION

DDLS – Plant pathology services.

Crop rotation

If there are high to very high RLN levels in a paddock, >10 nematodes/mL of soil or >10 000 nematodes/g dry root (severity score 3 & 4), DAFWA recommends growing a MR-R crop or pasture for one to two cropping seasons to reduce nematode numbers to a level that is not yield limiting (Table 3). Resistant crops reduce nematode numbers and may allow a tolerant varieties to be planted in the future. Do not sow susceptible crops where RLN populations are at damaging levels. Where there are low or moderate levels of RLN in a paddock then resistant crops, or tolerant cultivars of a susceptible or moderately resistant crop, may be suitable (refer to Crop Variety Sowing Guides). However, susceptible and moderately resistant crops are likely to increase RLN populations and adversely affect yield of subsequent crops. [22]

Table 3: *Reaction of major crop and pasture species to Pratylenchus neglectus, P. quasitereoides and P. penetrans.*

P. neglectus			P. quasitereoides *	P. penetrans *
Susceptible	**Moderately susceptible**	**Resistant**	**Susceptible**	**Susceptible**
Wheat	Barley	Field Pea	Wheat	Wheat
Canola	Oat	Narrow-leafed lupin	Barley	Oat
Chickpea	Medic	Faba and Narbon bean	Oat	Field pea
Mustard	Durum wheat	Lentil	Canola	Faba bean
Biserulla	Common vetch	Lathyrus		Narrow-leafed lupin
	Trigonella	Triticale		Chickpea
		Rye		Durum wheat
		Safflower		Triticale
		Clover and Lotus	**Moderately susceptible**	**Moderately susceptible**
		Legume pastures**	Narrow-leafed lupin	Barley
			Field pea	Canola
				Triticale

Source: GRDC

Weed control

It is important when planting resistant crops to ensure that susceptible weeds and volunteers are completely removed as, even at low densities, these may provide enough roots for RLN to multiply and remain at damaging levels. [23]

8.2 Cereal Cyst Nematode

Key points:

- Triticale is thought to be resistant to Cereal cyst nematode (CCN) [24] likely owing to its parent crop, cereal rye. [25]
- CCN is a threat to cereals in the Western and Southern growing regions.
- CCN is most damaging in low rainfall districts/seasons, especially with late breaks.
- Rotations — use break crops to minimise carry-over of CCN host species (canola, lupins, chickpeas etc) as non-host crops are more effective than resistant cereals in reducing levels of CCN.
- Be aware of and try to minimise consecutive cereal hosts during your rotation. CCN levels can become damaging after only one or two seasons of a susceptible crop.

22 Collins S, Wilkinson C, Kelly S, Hunter H, DeBrincat L. (2014). Root lesion nematode has a picnic in 2013. DAFWA.

23 Collins S, Wilkinson C, Kelly S, Hunter H, DeBrincat L. (2014). Root lesion nematode has a picnic in 2013. DAFWA.

24 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

25 Asiedu, R., Fisher, J. M., & Driscoll, C. J. (1990). Resistance to Heterodera avenue in the rye genome of triticale. *Theoretical and applied genetics*, *79*(3), 331–336.

- Grow resistant cereal cultivars to limit levels of CCN in the soil.
- Control volunteer cereal hosts and grass weeds during late summer/early autumn and in break crops.
- Sow early where possible to ensure better root development.
- Maintain optimum soil fertility to 'get-ahead' of CCN infections.

Cereal Cyst Nematode is a pest of graminaceous crops worldwide. This nematode is found in the Northern and Central regions of Western Australia. CCN becomes more problematic in areas where intensive cereal cropping occurs. Cereal cyst nematode 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.

CCN usually occurs early in the season and can occur on heavy or light soils.

CCN juveniles hatch from eggs contained in the cysts remaining from previous seasons 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 6 – 9 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. Cereal cyst nematodes have only one life cycle per year (Figure 4). However, each cyst contains several hundred eggs, so populations can increase rapidly on susceptible cereals. [26]

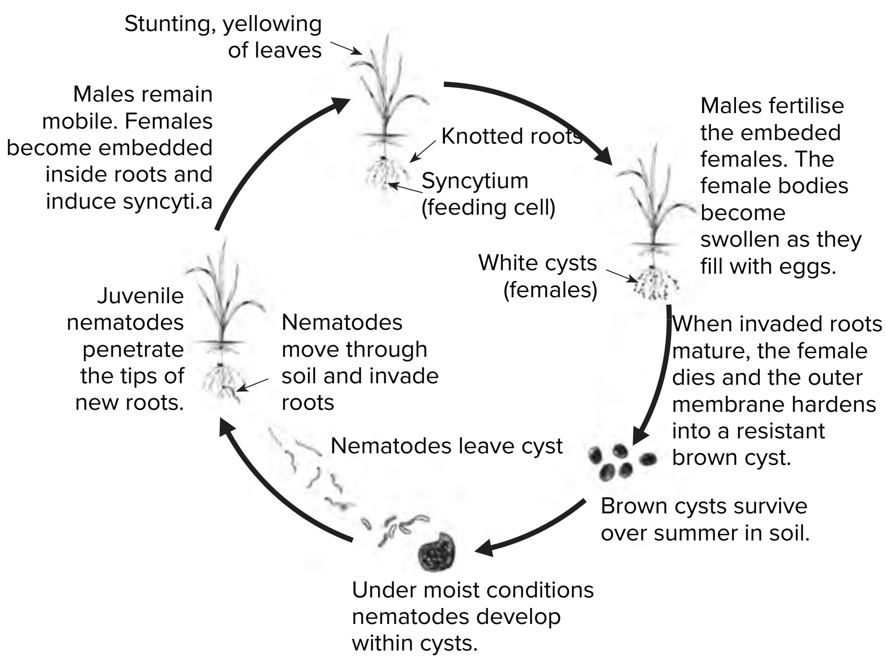


Figure 4: *Life cycle of the cereal cyst nematode.*

Source: Adapted from Kylie Fowler

CCN survives between susceptible cereal crops as eggs inside protective cysts that form on the roots of host plants. In the autumn, nematodes hatch from eggs in response to moisture and low temperatures (<15°C). Nematodes hatch over a period of several weeks, with the peak hatch occurring about six weeks after the autumn

26 Wherrett A and Vanstone V. Cereal cyst nematode. Soilquality.org. http://www.soilquality.org.au/factsheets/cereal-cyst-nematode

break. In a further eight weeks these nematodes will form viable eggs. Therefore, to prevent CCN multiplying, it is necessary to control host plants within 10 weeks of crop germination.

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. [27]

8.2.1 Symptoms and detection

Above ground, patches of unthrifty yellowed and stunted plants can be observed (Photo 5). Planting a susceptible crop in successive years will result in these patches becoming larger with time.
Closer examination of the roots will reveal symptoms that are typical of CCN. Below ground, cereal roots can appear 'knotted' (Photo 6), and 'ropey' or swollen (Photo 7). Development of root systems is retarded and shallow. In spring, characteristic 'white cysts' (about the size of a pin head) can be seen with the naked eye if roots are carefully dug and washed free of soil. These are the swollen bodies of the female CCN, each containing several hundred eggs. [28]

Photo 5: *CCN will cause distinct patches of yellowed and stunted plants. Note the likeness of symptoms to poor nutrition or water stress. (Photo by Vivien Vanstone, DAFWA, Nematology).*

Source: Soilquality.org.

27 Hollaway G, Henry F. (2013). Cereal root diseases. Agriculture Victoria. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

28 Wherrett A and Vanstone V. Cereal cyst nematode. Soilquality.org. http://www.soilquality.org.au/factsheets/cereal-cyst-nematode

Photo 6: *CCN produce 'knotting' of cereal roots.*

Photo by Vivien Vanstone, DAFWA, Nematology, Source: Soilquality.org

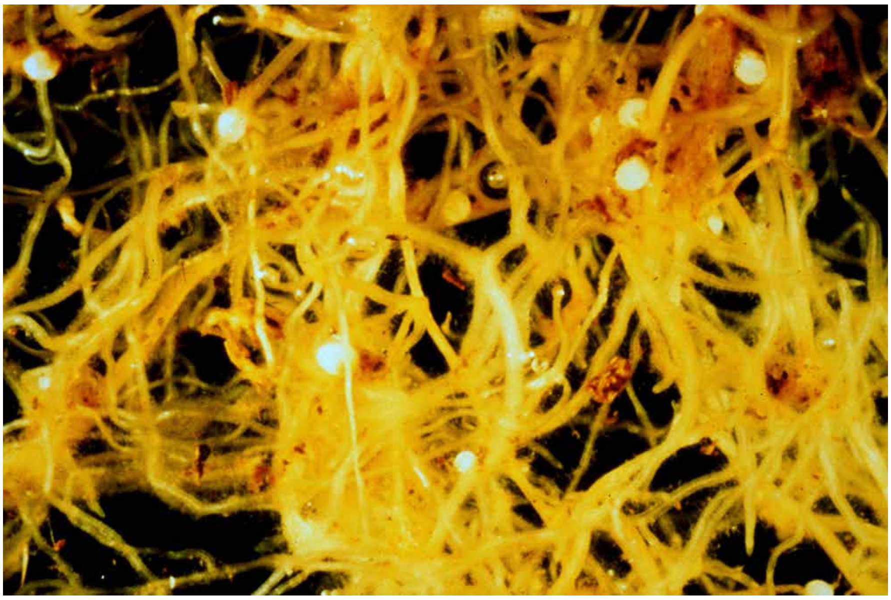


Photo 7: *Cereal roots infected with CCN appear 'ropey' and swollen.*

Source: CropPro

MORE INFORMATION

Diagnosing cereal cyst nematode

8.2.2 Varietal resistance or tolerance

Triticale is thought to be resistant to Cereal cyst nematode (CCN) [29] likely owing to its parent crop, cereal rye. [30]

8.2.3 Damage caused by CCN

CCN affects triticale, wheat, barley and oat varieties and can cause yield loss of up to 80% in intolerant varieties. [31] In serious outbreaks of CCN, it may be important to avoid cereals for two years to ensure an adequate reduction in the population. Just

29 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

30 Asiedu, R., Fisher, J. M., & Driscoll, C. J. (1990). Resistance to Heterodera avenue in the rye genome of triticale. *Theoretical and applied genetics*, *79*(3), 331–336.

31 GRDC. (2009). Plant parasitic nematodes Fact sheet – Southern and western region. Managing cereal cyst and root lesion nematodes.

two CCN eggs per of gram soil can cause significant economic loss to intolerant cereal crops. Levels of 1 – 5 eggs per gram of soil can reduce yield of intolerant cultivars by up to 20%. [32]

8.2.4 Management

Plan ahead and make sure there is at least a two-year disease break following susceptible cereals on paddocks infested with wild oats. 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 wild oats and 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 (See Figure 8 above).

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.

In areas prone to CCN, it is important to maintain a high proportion of CCN resistant cereals in the rotation.

Disease breaks for CCN

- Grass free pulse and oilseed crops or legume pasture.
- Resistant cereals (See local Cereal Diseases Guide for a list of CCN resistant cereal varieties).
- Chemical fallow prepared early in the season before nematodes have produced viable eggs.

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. Cereal cyst nematode is best controlled through effective rotation management. 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. The use of a break crop (e.g. canola, lupins, chickpeas) ensures a large proportion of the CCN population is removed. In serious outbreaks of CCN, it may be important to avoid cereals for two years to ensure an adequate reduction in the population.

Ryegrass, wild oats and other grass are also good hosts for CCN, although reproduction rates may be lower than on the cropping species. For this reason is important to realise that during a pasture phase in a rotation, the existence of cereal weeds will assist the development of a CCN population. Likewise, if there are grasses present following summer rains or around paddock borders it provides a carry over for the nematode population.

Ensuring optimum soil fertility is maintained helps to minimise the effects of CCN. Allowing the emerging crop access to adequate nutrition allows the root systems to establish and 'get ahead' of any potential nematode infections. Although this does not decrease the nematode population, losses associated with CCN infections will be minimised.

Finally, in paddocks where there is a known population of cereal cyst nematode and the planting of a cereal cannot be avoided it is important to choose cultivars displaying CCN resistance. [33]

32 Wherrett A, Vanstone V. (2016). Cereal Cyst Nematode. http://www.soilquality.org.au/factsheets/cereal-cyst-nematode

33 Wherrett A and Vanstone V. Cereal cyst nematode. Soilquality.org. http://www.soilquality.org.au/factsheets/cereal-cyst-nematode

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. [34]

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 *P. thornei* levels. As well as reducing yield, *P. thornie* reduces grain quality and nitrogen use efficiency, and increases the severity of crown rot infections. [35]

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 crop yields. [36]

Where *P. thornei* 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 Pt in a susceptible variety it could be 30–50% if crown rot is combined with a *P. thonei*-intolerant variety (Photo 8).

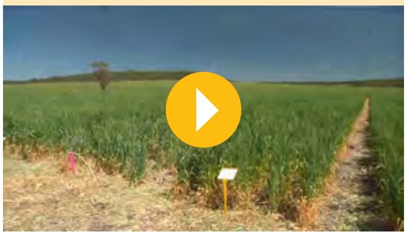
The research has also shown that not only does *P. thornei* cause high yield loss in susceptible varieties, but *P. thornei* numbers can increase much faster than in an area in which tolerant varieties are growing. These increased numbers can lead to even greater damage in future crops. [37]

Photo 8: *Grass plant showing both parasitic nematode damage to roots and crown rot in above ground tissues.*

Source: NCSU

VIDEOS

WATCH: GCTV9: Crown rot and root-lesion nematode.



34 GRDC. (2016). Tips and Tactics: Crown rot in winter cereals – Southern region.

35 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

36 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

37 Freebairn B. (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

8.3.1 Management

Variety choice is the key management option when it comes to managing *P. thornei* 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. Root lesion nematodes, need to be taken far more seriously and better factored into crop rotation considerations as well as variety choice. [38]

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 9).

Photo 9: *Sampling for PreDicta B*

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

Growers can access PreDicta B diagnostic testing services through a SARDI accredited agronomist. They will interpret the results and give advice on management options to reduce risk of yield loss.

SARDI processes PreDicta B samples weekly between February to mid-May (prior to crops being sown) every year.

These timeframes assist growers with their cropping program.

PreDicta B is not intended for in-crop diagnosis. See the 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 *P. thornei* 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 *P. neglectus* versus *P. thornei* 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

38 Freebairn B. (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

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.

Growers still need to be aware that significant yield loss can occur in more tolerant varieties under high infection levels, particularly when plants suffer serious moisture/temperature stressed during grain-fill. Some newer varieties have a measurable improvement in their tolerance to crown rot but current levels are still not a complete solution to crown rot. [39]

39 Simpfendorfer S, Gardner M, Brooke G, Jenkins L. (2014). GRDC Update Papers: Crown rot and nematodes – are you growing the right variety? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Crown-rot-and-nematodes

Diseases

Key messages

- Triticale can be less susceptible to the common fungal diseases of cereals which make it suitable for use in rotations where stubble is retained.
- Some varieties have good resistance to stem, leaf and stripe rusts, mildew and *Septoria tritici* blotch as well as both resistance and tolerance to Cereal Cyst Nematode (CCN). [1]
- Soil testing is essential for diagnosing many cereal diseases.
- Keeping consistent paddock records and implemented crop rotations are some of the most important and simple strategies in fighting crop diseases.
- Soil-borne diseases, cost Western Australian grain growers an estimated average of $105 million per year in yield and quality losses.

In the early development stages of triticale in Australia, the crop was relatively free of disease compared with other winter cereals. As the crop expanded in the 1980's, a range of fungal and other diseases became more important and required management. The main diseases have been the three rusts (leaf, stem and stripe rust), crown rot, barley yellow dwarf virus (BYDV), and nematodes. The likely arrival of stem rust Ug99 plus new races of stem rust has major implications for triticale production since the genetics of rust resistance is less well documented in triticale compared with wheat. [2]

Many growers use triticale as a disease break in their rotations and value the benefits of triticale for its contribution to soil conservation. Thus, triticale assists in maintaining soil health by the reduction of nematodes, such as *Pratylenchus neglectus* and *thornei* (root lesion nematodes) and *Heterodera avenae* (cereal cyst nematode), and a range of fungi and bacteria that build up in the soil, reducing yields when the same crop species is grown repeatedly. Other favoured characteristics of triticale are its resistances to barley yellow dwarf virus, mildew and rusts, which may cause significant yield reductions in wheat, barley and oats. [3]

Triticale is thought to be tolerant to rusts, *Septoria tritici*, smuts, bunt, powdery mildew, take all, root rots, barley yellow dwarf virus, wheat mosaic virus and barley stripe mosaic virus. [4] Triticale has vastly superior tolerance over wheat to *Septoria tritici* blotch. [5]

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

2 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

3 Cooper KV, Jessop RS, Darvey NL in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org. http://www.fao.org/docrep/009/y5553e/y5553e00.htm

4 Varughese, Pfeiffer and Pena (1996) in Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org. http://www.fao.org/docrep/009/y5553e/y5553e00.htm

5 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

Table 1: *Triticale variety agronomic guide and disease reaction.*

Variety	Maturity	Height	Head colour	Stem rust	Stripe rust	Leaf rust	Yellow leaf spot	Septoria tritici	CCN resistance	*Pratylenchus neglectus* resistance	*Pratylenchus thornei* resistance
Astute(D	M	M-T	W	RMR	RMR#	RMR	MRMS	-	R	RMR	MS
Berkshire(D	E-M	T	W	R	MRMS#	R	MR	RMR	-	MR	MS
Bison(D	M	T	W	RMR	R#	RMR	MR	MR	R	MR	RMR
Canobolas(D	E-M	M-T	W	R	MRMS#	RMR	MR	RMR	-	MR	MSS
Chopper(D	E	S-M	W	MR	MRMS#	R	MR	RMR	R	MRMS	MSS
Endeavour(D	L		W	R	RMR#	R	MR	R	-	MR	SVS
Fusion(D	M	M-T	W	R	RMR#	R	MRMS	R	R	RMR	MS
Goanna	E-M	T	W	R	RMR#	R	MR	R	R	MRMS	SVS
KM10	E-M			R	R#	MRMS	MRMS	MR	-	MR	MSp
Rufus	M	T	W	R	MRMS#	R	MR	RMR	R	MSS	MSS
Tahara	M	T	W	R	MRMS#	R	MR	RMR	R	MR	S
Tobruk(D	M-L	-	W	R	MR#	R	MR	R	-	MR	SVS
Tuckerbox	M	T	W	MR	MR#	R	MR	RMR	-	MRMS	S
Yowie	M	M-T	W	R	MR#	R	MR	RMR	R	MR	MSS

Maturity: E = early, M = mid season, L = late, VL = very late Height: M = medium, T = tall Colour: W = white, Br = brown Disease resistance order from best to worst: R > RMR > MR > MRMS > MS > MSS > S > SVS > VS. p = provisional ratings - treat with caution. R = resistant, M = moderately, S = susceptible , V = very. # Varieties marked may be more susceptible if alternative strains are present.

Source: Agriculture Victoria

General disease management strategies:

- Use resistant or partially resistant varieties.
- Use disease-free seed.
- Use fungicidal seed treatments to kill fungi carried on the seed coat or in the seed.
- Have a planned in-crop fungicide regime.
- Conduct in-crop disease audits to determine the severity of the disease. This can be used as a tool to determine what crop is grown in what paddock the following year.
- Conduct in-fallow disease audits to determine the severity of the disease, e.g. yellow leaf spot and crown rot. This can also be used as a tool to determine what crop is grown in what paddock the following year.
- Send plant or stubble samples away for analysis to determine the pathogen or strain you are dealing with or the severity of the disease
- Keep the farm free from weeds, which may carry over some diseases. This includes cereals over summer that may act as a green bridge.
- Rotate crops. [6]
- Stay up to date with local disease guides.

6 DAFF (2012) Wheat—diseases, physiological disorders and frost. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

9.1.1 Tools for diagnosing cereal disease

Crop Disease Au App

Google play | App Store

The Australian Field Crop Disease Guide app allows the user to quickly identify crop diseases; compare disease-resistance ratings for cereal, pulse and oilseed varieties; and, potentially, facilitate the early detection of exotic crop diseases.

The app brings together disease resistance ratings, disease information and also features an extensive library of quality images that make it easier for growers to diagnose crop diseases and implement timely management strategies. Live feeds from the Australian National Variety Trials (NVT) database means the apps is always up to date with the latest varieties.

If a disease cannot be identified there is also a function that allows the user to take a photo of their crop and email it to a friend or an advisor.

The new Crop Disease Au app functions similarly to the previous DEDJTR app but provides information for all Australian grain growing regions.

MyCrop

Google play | App Store | Web-based

Released by DAFWA and funded by the GRDC, MyCrop is a collection of interactive tools that can be accessed online or via apps that enable users to diagnose **cereal** production constraints while in the field.

The main feature is an intuitive diagnostic key, which quickly diagnoses a range of possible constraints based on real-time crop and paddock symptoms. Covering a broad range of disease, pest and other agronomic issues, MyCrop can help users to accurately identify constraints and determine possible management solutions. Key features include:

- Extensive image library and constraint factsheets.
- Selecting paddock and plant clues to easily identify the likely cause of cropping problems.
- Over 150 constraints ranging from pests and diseases to soil deficiencies, environmental and management factors.
- Online diagnostic tools

CropPro

DEDJTR and GRDC's newly released online tool CropPro has diagnostic and economic features that allow growers to efficiently identify and manage constraints to both crop productivity and profitability. The core functions of CropPro are to diagnose the cause of wheat and canola crop problems, support risk analysis and provide evidence-based information for management of crop constraints. It combines paddock and crop symptoms in one resource, enabling users to work through a simple process of elimination. CropPro also has an economic feature allowing growers to compare return-on-investment outcomes for different management options and an Agronomist Toolkit that includes an extensive list of resources, online decision support tools and apps. For the first time the Field Crop Diseases Manual is available online! This provides an all-in-one resource for disease identification, biology and management information for cereal, pulse and oilseed crops. The manual is written and maintained by leading subject experts from DEPI and Marcroft Grains Pathology, and provides a detailed exploration of diseases and the influence of pest and abiotic factor. A series of economic videos also feature on CropPro, providing growers with clear information about how management decisions might influence their profitability.

MORE INFORMATION

MyCrop

GRDC Cereal root and crown diseases: Back pocket guide.

9.2 Rust

In Australia, there are three rust diseases of triticale and wheat:

- stripe rust
- stem rust
- leaf rust.

They are caused by three closely related fungi all belonging to the genus *Puccinia*.

The 'rusts' are so named because the powdery mass of spores which erupt through the plant's epidermis have the appearance of rusty metal. These spores can be spread over considerable distances by wind but may also be spread on clothing and equipment.

Rusts have a number of features in common. They can only infect a limited number of specific host plants (mostly volunteer triticale, wheat and barley) and can only survive on green growing plant tissue. Biotrophic pathogens (including stem rust, stripe rust and leaf rust) require a living plant host and cannot survive on soil, seed or dead tissue and need a 'green bridge', grassy weeds or overlapping crops to persist. Plants facilitating the survival of rust fungi through the summer are known as the 'green bridge'. [7]

Stripe rust and leaf rust can be a significant threat to crops in Western Australia in some seasons. [8]

Given favourable conditions rust can cause large losses in susceptible varieties. However, growers have shown that by planning to manage this disease they can effectively minimise its effects.

The University of Sydney's recent Cereal rust report warns growers to monitor crops carefully. Wheat leaf rust, barley leaf rust, oat crown rust and oat stem rust are all being detected across a wide area of Western Australia. Samples of wheat leaf rust off Mace from Western Australia were received in mid-July (2016) from Coomalbidgup; late August from Grass Patch; and early September from Nabawa. Pathotype identifications are underway. Recent weather conditions across large areas of the cereal growing regions are likely to favour rust development. Monitoring of crops for all cereal rusts is advised and samples of all rusts observed in cereal crops should be submitted for pathotype analysis to the Australian Cereal Rust Survey. [9]

New wheat leaf rust pathotype detected in WA – 2015

A new leaf rust pathotype of *Puccinia triticina*, known as 104–1, 3, 4, 6, 7, 8, 10, 12 +Lr37 was first detected in WA in September 2015. The airborne disease was discovered in South Australia in 2014 and has since been detected in several crops in WA.

The new pathotype differs from those detected previously in WA in being fully virulent on the complementary resistance genes Lr27+Lr31, the adult plant resistance gene Lr12, and in combining virulence for Lr1 with Lr13, Lr17a, and Lr26. As a result wheat varieties dependent on these resistance genes will become more vulnerable to leaf rust infection by this strain.

This find follows the detection in 2013 of another new leaf rust pathotype, which was the first occurrence of virulence for the resistance genes Lr13, Lr17a, Lr17b, and Lr26 in WA.

7 DAF. (2015). Wheat- diseases, physiological disorders and frost. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

8 DAFWA. (2016). Managing stripe rust and leaf rust in wheat in Western Australia. https://www.agric.wa.gov.au/grains-research-development/managing-stripe-rust-and-leaf-rust-wheat-western-australia

9 Cuddy W, Park R, Singh D. (2016). Cereal rust situation, September 2016.

What should grain growers do now?

The find of a second new leaf rust pathotype in WA in recent years has serious implications for growing wheat crops in WA and serves as a warning for growers to carefully consider management options each season:

- Be vigilant and destroy green bridge (volunteer cereals and weeds) at least four weeks prior to seeding.
- In high risk areas, where varieties rated S to MS haven't been replaced with more resistant options consider a registered seed dressing or in-furrow fungicide or budgeting for foliar fungicide application is advisable. An effective strategy is to delay general seed dressing or in-furrow treatment of susceptible varieties until autumn. Where 'green bridge' cereals survive through autumn in local districts there is an increased likelihood that stripe or leaf rust could establish early in young susceptible crops.
- Keep up to date with variety disease rating changes, new ratings should be available in the 2016 Variety Sowing Guide.
- Report rust finds to PestFax and take samples to submit to the Australian Cereal Rust Control Program for pathotype testing.

Further information on strategies to manage leaf rust in wheat is available on the Managing leaf rust and stripe rust page or Implications of the known leaf rust pathotypes in WA page. [10]

The Rust Bust is an initiative of the Australian Cereal Rust Control Program (ACRCP) Consultative Committee, with support from the Grains Research & Development Corporation. Rust Bust aims to raise awareness of wheat rust management strategies that reduces risk of disease outbreak.

MORE INFORMATION

The Rust Bust

How to manage rust – The Rust Bust WA

Cereal rust report – September 2016

WA rust resistance ratings - wheat

9.2.1 Varietal resistance or tolerance

Some triticale varieties have good resistance to stem, leaf and stripe rusts (Table 2).

Table 2: *Triticale variety Rust disease susceptibility ratings.*

Variety	Stem rust	Stripe rust	Leaf rust
Astute⒫	RMR	RMR#	RMR
Berkshire⒫	R	MRMS#	R
Bison⒫	RMR	R#	RMR
Canobolas⒫	R	MRMS#	RMR
Chopper⒫	MR	MRMS#	R
Endeavour⒫	R	RMR#	R
Fusion⒫	R	RMR#	R
Goanna	R	RMR#	R
KM10	R	R#	MRMS
Rufus	R	MRMS#	R
Tahara	R	MRMS#	R
Tobruk⒫	R	MR#	R
Tuckerbox	MR	MR#	R
Yowie	R	MR#	R

Maturity: E = early, M = mid season, L = late, VL = very late Height: M = medium, T = tall Colour: W = white, Br = brown Disease resistance order from best to worst: R > RMR > MR > MRMS > MS > MSS > S > SVS > VS. p = provisional ratings - treat with caution. R = resistant, M = moderately, S = susceptible , V = very. # Varieties marked may be more susceptible if alternative strains are present.

Source: Agriculture Victoria

10 Beard C, Thomas G. (2015). 2015 New wheat leaf rust pathotype detected in WA. DAFWA. https://www.agric.wa.gov.au/grains-research-development/implications-known-wheat-leaf-rust-pathotypes-wa

9.2.2 Symptoms

Table 3: *Diagnosing leaf diseases in wheat.*

Disease	Spore colour	Symptoms	Plant part affected
Stripe rust	yellow/orange	Small closely packed circular pustules during the vegetative stage, becoming stripes along leaves of older plants.	Upper surface of leaf, leaf sheaths, awns and inside glumes
Leaf rust	orange/brown	Random, circular to oval pustules.	Upper surface of leaf and leaf sheaths
Stem rust	reddish/brown	Random, oblong pustules with torn margins.	Both sides of leaf, leaf sheaths, stems and outside of head
Yellow spot	small tan (yellow brown) oval spots surrounded by a yellow margin	Spots up to 10 mm, varied shapes and may coalesce.	Both sides of leaf, leaf sheaths, stems and outside of head

Source: DAFF

9.2.3 Stripe rust

Stripe rust has become more important in recent years owing to new races arriving in eastern Australia.

Photo 1: *Stripe rust in wheat.*

Source: DAFF

Stripe rust is caused by the fungus *Puccinia striiformis*. It is easily distinguished from other wheat rusts by the orange-yellow spores, which produce small, closely packed pustules developing into stripes along the length of the leaf veins. The spores occur on the upper surface of the leaves, the leaf sheaths, awns and inside of the glumes (Photo 1).

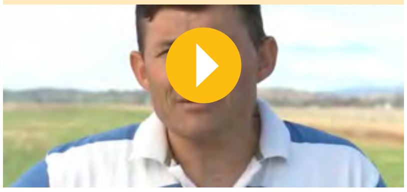
Stripe rust requires cool and wet conditions to infect the crop. Free moisture on the leaves and an optimal temperature (10–15°C) are required for infection. Pustules erupt within 10–14 days after infection.

If the weather is conducive to stripe rust, the disease can cause up to 25% yield loss on varieties scoring moderately susceptible = 5 (MR-MS) or lower. This is provided there is inoculum from a neglected green bridge or from an infected crop.

There are several fungicides recommended for the control of stripe rust. Fungicides can be incorporated with the fertiliser or applied as seed dressings to delay the

MORE INFORMATION

Stripe rust



onset of disease. Later on if 'money' leaves require protection, recommended foliar fungicides can be applied for the control of stripe rust (see section 1.2.6 Managing cereal Rusts, below).

In 2007, a new pathotype of stripe was detecting in many triticale cultivars. Despite dry conditions, stripe rust infections have swept through triticale crops, in particular Jackie. The pathotype was virulent on most triticale varieties. The Jackie pathotpye, unlike most new pathotypes, has been widespread and affected most triticale cultivars. Greenhouse trials found that Everest, Tickit and Tahara still had effective resistance to Jackie. Results on Crackerjack and Treat showed some level of intermediate resistance, which means that some plants in these varieties were resistant while others are susceptible. Seedling resistance for all other varieties changed from resistant or intermediate to susceptible. This included varieties such as Breakwell⑮, Speedee, Kosciusko and Prime322. Some newly released varieties of triticale were more resistant to the new pathotype. [11]

Managing stripe rust

Stripe rust may be a problem in triticale and there are now options to treat seed to provide seedling protection against stripe rust. [12]

The key to stripe rust management is variety choice. Avoid growing highly susceptible varieties; i.e. replace susceptible varieties with a moderately or highly resistant variety.

Growers should check to ensure their current variety has adequate field resistance to both the Jackie and Tobruk⑮ pathotypes of stripe rust or consider using foliar fungicides to control the disease in-crop if required.

Seed treatment should be considered for controlling seedling stripe rust in susceptible varieties, especially those sown early for grazing. [13]

MORE INFORMATION

Managing stripe rust and leaf rust in wheat in Western Australia

Newer varieties generally have improved stripe rust resistance. Varieties with at least an MR/MS (moderately resistant/moderately susceptible) should be used.

Usually changing to a more stripe rust resistant variety also gives a yield advantage. For example changing from Jackie to Endeavour⑮ makes good sense. Endeavour⑮ offers a 15% yield increase over Jackie, has excellent dry matter production for early grazing, and is resistant to all current strains of stripe rust.

Seek local advice on managing stripe rust in triticale. Remember that just because a variety is rust resistant does not mean it will be completely free of stripe rust.

11 DPI NSW. (2007). New triticale stripe rust pathotype. http://www.dpi.nsw.gov.au/content/archive/agriculture-today-stories/ag-today-archives/december-2007/triticale-stripe-rust-pathotype

12 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

13 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

nder very high disease pressure, isolated leaves of resistant varieties can be infected. This does not automatically mean the resistance has broken down or that the crop needs spraying. [14] In these cases rust samples should be sent to:

Australian Cereal Rust Survey

Plant Breeding Institute

Private Bag 4011

Narellan NSW 2567

9.2.4 Stem rust (black rust)

Triticale is thought to have good resistance against stem rust. [15] All the present commercial varieties have been screened for the current races of stem rust and they have adequate levels of resistance. The possible arrival of newer races of stem rust requires further screening for these races. The levels of resistance to new races are unknown. [16]

Photo 2: *Stem rust in wheat.*

Source: DAFF

Stem rust is caused by the fungus *Puccinia graminis* f. sp. *tritici*. In addition to triticale it can also attack wheat, barley and cereal rye.

Stem rust produces reddish-brown spore masses in oval, elongated or spindle-shaped pustules on the stems and leaves. Unlike leaf rust, pustules erupt through both sides of the leaves (Photo 2). Ruptured pustules release masses of stem rust spores, which are disseminated by wind and other carriers.

Stem rust develops at higher temperatures than the other wheat rusts within a range of 18–30°C. Spores require free moisture (dew, rain or irrigation) and take up to six hours to infect the plant and pustules can be seen after 10–20 days of infection.

Some cereal varieties have reasonable resistance to stem rust (rating 5 or higher). However, in the past, stem rust has had the ability to cause significant economic damage (50–100% of yield). This has happened when conditions are conducive for the disease and susceptible varieties are grown, or a new stem rust pathotype has developed, which has overcome the wheat's resistance.

Inoculum must be present for the disease to develop. Practicing crop hygiene by removing volunteer wheat, which forms a green bridge for the fungus through the summer, can eliminate or delay the onset of stem rust.

Foliar fungicides to control stem rust are available, see section 9.2.6 Managing cereal Rusts, below.

VIDEOS

WATCH: GCTV5: Green Bridge control for less stem rust.

MORE INFORMATION

Stem rust

14 Waratah Seed Co. Ltd. (2010). Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

15 Adhikari, K. N., & McIntosh, R. A. (1998). Inheritance of wheat stem rust resistance in triticale. *Plant breeding*, *117*(6), 505–513.

16 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

9.2.5 Leaf rust (brown rust)

The current commercial triticale varieties have good resistance to leaf rust and newer varieties should maintain this attribute. [17]

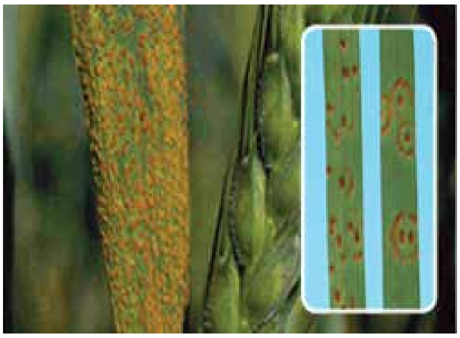


Photo 3: *Leaf rust in wheat.*

Source: DAFF

Leaf rust is caused by the fungus *Puccinia triticinia* (previously called *Puccinia recondita* f. sp. *tritici*). The disease can infect triticale, rye and wheat.

Leaf rust produces reddish-orange coloured spores which occur in small, 1.5 mm, circular to oval-shaped pustules. These are found on the top surface of the leaves, distinguishing leaf rust from stem rust which is found on both surfaces of the leaf (Photo 3).

In most parts of Australia leaf rust is effectively controlled with resistant varieties, but it can cause problems in areas where susceptible varieties are grown (Figure 1). Cereal varieties mostly have reasonable resistance (rating of MR-MS - 5 or higher).

The spores require 15 to 20°C temperature and free moisture (dew/rain/irrigation) on the leaves to successfully infect cereal. The first signs of the disease (sporulation) occur 10–14 days after infection. Removal of volunteer cereal plants, which forms a green bridge for the fungus through the summer, can eliminate or delay the onset of leaf rust.

Foliar fungicides to control stem rust are available, see section 1.2.6 Managing cereal Rusts, below.

17 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Figure 1: *Reported detections of leaf rust in 2016.*

Source: USYD

MORE INFORMATION

Leaf rust

9.2.6 Managing cereal rust

Rust diseases of cereals can be eliminated or significantly reduced by removing the green bridge. This should be done well before the new crop is sown, allowing time for any herbicide to work and for the fungus to stop producing spores.

Rust fungi continuously change, producing new 'pathotypes'. These pathotypes are detected when disease is found on a previously resistant variety. Even if a resistant variety has been sown, the crop should be monitored on a regular basis starting no later than growth stage 31 (1st node detectable) and continue to at least growth stage 49 (first awns visible). This is because the 'money' leaves (the flag, fleg -1, -2 and -3 leaves) are the main factories contributing to yield and quality. It is very important that these leaves are protected from any diseases. [18]

Foliar fungicide guidelines

Fungicide timing

- Apply fungicide as soon as possible after the first detection of stripe or leaf rust taking into consideration the stage of crop development and variety susceptibility.
- Economic responses are reduced with later fungicide application.
- Spraying after crop flowering is normally not economic for stripe or leaf rusts. Late rust infection should be carefully inspected to check it is not stem rust. For more information refer to Managing stem rust of wheat.
- Optimise control of stripe rust on leaves is important to reduce risk of infection of heads by applying fungicide at or before crop heading. Although spores may adhere to seed, they rarely induce grain discolouration and do not become seed bourne. Head infection will shrivel grain, so screenings will increase with severe infections.

18 DAFF QLD. Wheat – diseases, physiological disorders and frost. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

Fungicide rate

Use high rates of fungicide if application is delayed or if infection is advanced. Use high rates of fungicide for longer duration of protection, for example, when season conditions favouring infection are likely to persist or for more susceptible varieties. Cost should be tuned to crop yield potential and crop season length.

Fungicide products

A list of registered foliar fungicides including registered rates is available. Consider what other diseases are present or the crop is at potential risk of when choosing which fungicide product to use.

Green bridge proximity

Summer rains permit the development of volunteer cereal hosts and autumn rains permit the early build-up of rust on these volunteers known as the 'green bridge'. This happens readily after wet summers. Cropping areas that receive summer rain resulting in self-sown green bridge cereals are at risk of early infection with stripe or leaf rusts. Wheat regrowth is the primary risk for carryover of both wheat leaf rust and wheat stripe rust. The amount of rust present in the previous season also determines the risk of leaf and stripe rusts. The more rust in a given year means there is more chance of carryover into the next season.

Weather

While resistance will influence individual crop risk, the overall risk of serious rust outbreaks is influenced by summer and winter weather factors (rainfall and temperature) which can be considered in your region each season. Both stripe and leaf rusts require moisture (rain or heavy dew) or high humidity for spores to germinate and infect leaves. Usually 4–6 hours of leaf wetness are required at optimum temperatures (warm days and dewy nights). Each rust has an optimum temperature for infection and growth (Table 4). Rust outlooks are provided as part of the plant pathology group's seasonal Crop diseases: forecasts and management page.

A stripe or leaf rust epidemic is more likely if the winter and/or spring is suitably wet. Seasonal outlooks are available on the Seasonal Climate Information page. Leaf rust has a warmer mean daily temperature optimum than stripe rust (Table 6). The mild winters in Western Australia result in leaf rust being relatively active in winter and into spring, particularly in the northern agricultural areas. Early sown crops, on which infections establish prior to the cooler winter months, are more at risk from early leaf rust which can develop rapidly in spring. The lower temperature optimum for stripe rust results in the disease being relatively more active in winter than later in the season. Warm spring conditions, particularly in the northern agricultural areas, can increase the time taken between infection and resultant new spores being produced (the latent period). Rust spores easily spread on wind.

Table 4: *The approximate time taken for an infection to result in new spores (latent period) and indicative optimal temperature ranges for rust foliar diseases in wheat*

Disease	Latent period (days)	Optimal daily temperature (°C)
Stem rust	7–10	20–35
Stripe rust	10–14	12–20 (dormant >23)
Leaf rust	7–10	15–25

Biosecurity measures

Because there are different strains of leaf, stem and stripe rusts, care must be taken when travelling interstate or receiving interstate or overseas visitors, since spores carried on clothing could introduce new strains of rusts. Implement biosecurity measures to minimise rust becoming established or spreading on your farm. Rust spores are small, light and may survive for several days without a host. Rust spores can spread long distances by wind, on machinery/vehicles, on tools, clothing and footwear. Remember that if you walk through an infected crop, follow biosecurity protocols and thoroughly clean your boots, hands and trousers before entering another paddock or travelling as rust spores can be unknowingly transferred via people locally and also from overseas. Also check biosecurity measures taken by your visitors and agronomists.

Be particularly vigilant when returning from eastern Australia or internationally, as rust pathotypes with different virulences exist outside WA.

If entering a paddock suspected to be infected with rust, biosecurity suggestions include:

- Wear protective overalls and rubber boots
- After crop inspection clean any material off boots with a brush. Prepare footbath of bleach (10% household bleach, 90% water) and spray bottles of methylated spirits brew (95% metho, 5% water) for use to disinfect footwear, pants and hands
- Decontaminate vehicles, tools and machinery
- Walk instead of driving through crops
- Ask visitors/agronomists to leave their vehicle at the gate and only travel on your property in your vehicle.

Utilise variety resistance

Resistance to one rust is normally independent of resistance to other rusts. Varieties may express a range of resistance to stripe or leaf rust in three broad categories:

- Resistant at all plant stages from seedling to adult (MR-R). Fungicide is not required. Normally based on a single gene resistance, experience around the world has shown this resistance can be rendered ineffective (break down) through rust mutation.
- Partially resistant (MRMS), susceptible at young crop stages and gradually increasing in resistance as the crop develops during late stem elongation, expressing maximum adult plant resistance around heading/flowering. Varieties usually develop rust slowly unless they become infected early.
- Very susceptible to susceptible (VS-S) throughout all stages, rapid rusting causing significant yield losses. Promotes epidemic development and pathogen mutation.
- Variety ratings are available. There have been some recent changes due to the presence of two new leaf rust pathotypes in WA (one in 2013 and one in 2015). For further information see Implications of the known wheat leaf rust pathotypes in WA.

Destroy green bridge well in advance of seeding

The overlap of summer volunteer or autumn sown susceptible wheat with conventional wheat plantings in winter is a crucial factor in establishing early severe infection of stripe or leaf rust. Destroy self-sown wheat (particularly the most susceptible varieties) well in advance of seeding (4–6 weeks recommended) as occurrence of rain leading into a cropping season increases susceptible regrowth and allows very early sowing opportunities. Further information on green bridge managment is available at Control of green bridge for pest and disease management.

Early season fungicide protection is important in high risk situations

For S-MRMS varieties, if there is an increased risk of localised rust carryover associated with green bridge cereals in your region, use of a seed dressing or in-furrow fungicide at seeding or fungicide spray at stem elongation can limit early prior to flag leaf emergence. Risk of early season infection cannot be assessed until autumn. If possible, delay general seed treatment of susceptible to intermediate varieties until autumn to determine the risk of rust associated with high early rainfall and regional green bridge cereals. Highly effective options include long-acting seed dressings or in-furrow fungicides that can provide protection until around flag leaf emergence stage depending on rate of application and disease pressure. Expenditure decisions (including product choice) should be made according to risk, yield potential and presence of other diseases. For details on registrations refer to the Seed dressing and in-furrow fungicides for cereals in WA page.

Foliar fungicides can also protect from early infection. In the absence of fungicide at seeding, crops at high risk of early infection can be treated with a foliar fungicide spray at first node (Z31) to protect the crop from early infection until around flag leaf emergence. This strategy is applicable to varieties with ratings S-MRMS and can be used instead of fungicide at seeding. This can delay and sometimes avoid costs if the disease risk does not eventuate. This early spray will only protect the leaves which are emerged at the time of the foliar application and may require a follow up spray if seasonal conditions favour continued rust development. For details on registrations refer to the Seed dressing and in-furrow fungicides for cereals in WA page.

Trials in 2014 with Mace and Lr 76–1, 3, 5, 7, 9, 10, 12 +Lr37 pathotype showed infection and yield losses were greatest when disease was present from Z31, infection after Z39 had less impact.

Control late infection in susceptible to intermediate varieties with fungicide

Foliar fungicide retards disease development for about 3–6 weeks after application, depending on product and rate. These diseases can be controlled effectively and economically if fungicide is applied shortly after infection commences but follow-up application will probably be required in long season environments or on very susceptible varieties. If crops have not received early fungicide, commence monitoring for stripe or leaf rust at first node stage, Z31 and apply foliar fungicide at the first sign of infection according to the stage of crop development and variety susceptibility. If crops have received early fungicide, commence monitoring for stripe or leaf rust at early to full flag leaf emergence and apply fungicide at the first sign of infection according to the stage of crop development and variety susceptibility. When taken up by the leaf, the fungicide can stop development of early infections but more established infections can continue such that rust pustules may persist for several days after fungicide application. A list of registered foliar fungicides is available to assist choosing a product.

How to monitor crops

The aim of crop monitoring is to detect infection at the earliest stage feasible. Inspect the most susceptible and earliest sown crops carefully over a wide area of the paddock. Examine leaves at the top and bottom of the canopy for scattered light infections. In green bridge areas also look for infrequent heavily-infected hot spots. Crops prone to infection at young stages (rated very susceptible to moderately resistant) should be inspected at seven to 10 day intervals from early stem elongation (growth stage Z31) or from early flag leaf emergence (growth stage Z37) if seeding fungicide treatments registered to control rust diseases have been used.

A chargeable service is available to assist with disease diagnosis, send ~10 infected leaves to:

DAFWA Diagnostic Laboratory Services (DDLS)
Department of Agriculture and Food, Western Australia
Locked Bag 4, Bentley Delivery Centre WA 6983

Post in a paper envelope (no plastic) with date, location, name and contact details. Broadacre diagnostic submission forms are available from your local office or from the DAFWA Diagnostic Laboratory Services (DDLS) page.

Rust pathotype testing

Leaf rust and stripe rust occur as different strains because they can readily mutate and strains can easily move around the country and the world on the wind or people's clothing. Possible new strains need to be continuously monitored in order

VIDEOS

WATCH: GCTV Extension Files: Rust Sampling.

to understand the implications for existing varieties and to assist wheat breeders in developing new resistant varieties.

To monitor rust strains in Western Australia, growers and consultants are encouraged to send rust samples at no cost to the Australian Rust Survey, particularly from varieties showing unusually high levels of rust. Post leaf samples in paper envelopes to: University of Sydney, Australian Rust Survey, Reply Paid 88076, Narellan NSW 2567. Further instructions on submitting samples and printable dispatch forms are available from the University of Sydney website.

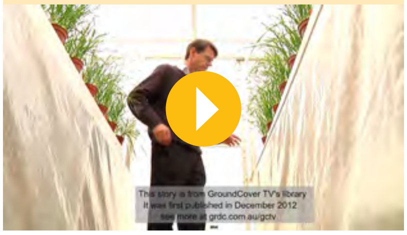
Reporting to PestFax

For the benefit of industry; growers, agronomists and consultants are encouraged to submit samples of rust finds to their local DAFWA office or directly to the National Cereal Rust Survey and to PestFax. Reports to PestFax can be made online to PestFax Reporter or PestFax map. To receive the weekly PestFax newsletter of disease and pest finds across the Western Australian wheatbelt, subscribe by emailing pestfax@agric.wa.gov.au. You can access past newsletters at the PestFax newsletter archive.

VIDEOS

WATCH: Adult plant resistance – fungicide.

WATCH: Cereal Rust – Adult plant resistance.



MORE INFORMATION

CSIRO Cereal rusts

Rust Bust.

9.2.7 Integrated disease management of rusts and yellow spot

Key points

- Destroy volunteer wheat plants by March, as they can provide a green bridge for rust carryover.
- Community efforts are required to eradicate volunteers from roadsides, railway lines, bridges, paddocks and around silos.
- Crop rotation is very important in the case of yellow spot and *Fusarium* head blight.
- Growing resistant varieties is an economical and environmentally friendly way of disease reduction.
- Seed or fertiliser treatment can control stripe rust up to four weeks after sowing and suppress it thereafter.
- During the growing season active crop monitoring is very important for an early detection of diseases.
- Correct disease identification is very important; you can consult the department's fact sheets, charts, website and experts.
- When deciding if a fungicide spray is needed, consider crop stage and potential yield loss.
- Select a recommended and cost-effective fungicide.
- For effective coverage, the use of the right spray equipment and nozzles is very important.
- Read the label, wear protective gear, be safe to yourself and environment.
- Avoid repeated use of fungicides with the same active ingredient in the same season.
- Always check for withholding periods before grazing and harvesting a crop applied with any fungicide.
- If you suspect any severe disease outbreak, especially on resistant varieties, your agronomist or local DPI.

Rust diseases occur throughout the cereal growing regions, frequently causing economic damage.

Wherever possible, sow resistant varieties MR (Moderately Resistant = 6) and above.

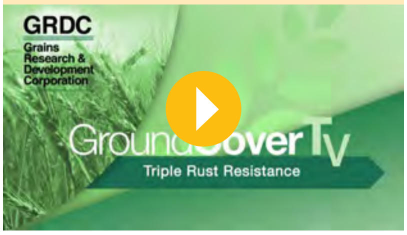
IN FOCUS

Breeding cereals for rust resistance in Australia

Rust diseases have caused significant losses to Australian cereal crops, and continue to pose a serious threat. Because Australian cereal crop yields are generally low, genetic resistance remains the most economical means of rust control. Resistant cultivars also contribute significantly to reducing over-summer rust survival. The Australian Cereal Rust Control Program conducts annual pathogenicity surveys for all cereal rust pathogens, undertakes genetic research to identify and characterize new sources of resistance, and provides a germplasm screening and enhancement service to all Australian cereal breeding groups. These three activities are interdependent, and are closely integrated with particular emphasis on linking pathology and genetics to ensure breeding outcomes. Recent changes in the wheat rust pathogens, including the development of virulences for *Yr17*, *Lr24*, *Lr37* and *Sr38* resistance genes, and the introduction of a new pathotype of the wheat stripe rust pathogen, have provided new and significant challenges for wheat rust resistance breeding. Similar challenges exist in breeding barley and oats for rust resistance. Examples are discussed to illustrate the ways in which rust isolates are providing information that can be used in breeding for rust resistance. In future, as more markers linked to durable rust resistance sources become available, it is likely that the use of marker-assisted selection will become more common-place in rust resistance breeding. [19]

VIDEOS

WATCH: GCTV18: Triple Rust Resistance.



9.3 Leaf spot

Leaf spot diseases affecting wheat in WA are yellow spot (*Pyrenophora tritici-repentis*), septoria nodorum blotch (*Parastagonospora nodorum; previously Phaeosphaeria nodorum,* synonyms *Stagonospora nodorum, Septoria nodorum*), and septoria tritici blotch (*Mycosphaerella graminicola*). They are caused by three different fungal pathogens but the disease symptoms and biologies are similar.

Septoria nodorum blotch and yellow spot may occur throughout the WA wheatbelt and frequently occur together. They have the capacity to significantly reduce yield and grain quality. Septoria tritici blotch has become less common throughout the WA wheatbelt and currently losses from this disease are rare.

Impacts from leaf spot diseases vary greatly from season to season and between locations. They are particularly a problem in continuous wheat crops in stubble retention farming systems. Yield loss will depend on the disease resistance of the variety and the presence and severity of the disease throughout the life of the crop. For susceptible varieties, when the disease development is continuous due to favourable conditions throughout the season, losses around 30% have been measured. When disease development is only favourable for part of the season, either before or after flag leaf emergence, losses around 20% can occur. Severe disease will cause grain quality reductions such as increased screenings and lower hectolitre weights that can add to high yield loss impacts. [20]

19 Park, R. F. (2008). Breeding cereals for rust resistance in Australia. *Plant Pathology*, *57*(4), 591–602.

20 Beard C, Jayasena K, Thomas G, Galloway J. (2016). Managing yellow spot and septoria nodorum blotch in wheat. https://www.agric.wa.gov.au/grains-research-development/managing-yellow-spot-and-septoria-nodorum-blotch-wheat?page=0%2C2

Septoria nodorum blotch and yellow spot often occur together and are generally impossible to distinguish by the naked eye. Septoria tritici blotch is considered rare in WA. [21]

9.3.1 Damage caused by disease

Leaf spot is most often observed in seedlings, but when conditions are suitable it can progress up the plant where it causes significant yield loss. [22] Grain yield can be substantially reduced and losses of more than 50% may occur in extreme situations. Pink grain with reduced value is also a frequent result of severe leaf spot epidemics. Where wheat follows wheat and some stubble is left on the soil surface, losses may be around 10–15%, and up to 30% in wet seasons.

9.3.2 Symptoms

Leaf spot diseases appear as irregular or oval-shaped spots that initially are small and often yellow (sometimes blackish-brown), but enlarge to form brown dead centres, with yellow edges (Photo 4). Typically, a badly affected leaf will die back from the tip as lesions merge, reducing the photosynthetic area and causing premature leaf death. Differentiation of septoria nodorum blotch, septoria tritici blotch, and yellow spot on the basis of symptoms is difficult even to a trained eye. Some physiological or nutritional yellowing symptoms can be confused with yellow spot and septoria so it is important to get a correct diagnosis. [23]

Photo 4: *Small tan-brown spots with yellow margins that become more elongated with age indicate the presence of yellow leaf spot. Yellowing of the leaf without lesions is not a symptom.*

Photo: Hugh Wallwork, Source: GRDC

Spot develops on both sides of leaves. Severe leaf spot may result in short, spindly plants with reduced tillering and root development (Photo 5). Where conditions are favourable, plants may be fully defoliated soon after flowering. [24]

21 Beard C. (2016). Yellow spot of wheat. DAFWA https://www.agric.wa.gov.au/grains-research-development/managing-yellow-spot-and-septoria-nodorum-blotch-wheat?nopaging=1

22 Holloway G. (2014). Yellow leaf spot of wheat. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/yellow-leaf-spot-of-wheat

23 Beard C, Jayasena K, Thomas G, Galloway J. (2016). Managing yellow spot and septoria nodorum blotch in wheat. https://www.agric.wa.gov.au/grains-research-development/managing-yellow-spot-and-septoria-nodorum-blotch-wheat?page=0%2C2

24 DAFF QLD. Wheat – diseases, physiological disorders and frost. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

Photo 5: *Spot form of net blotch causing dead leaves in susceptible variety.*

Photo Mike Ford, Source: GRDC

What to look for

Paddock

- Yellowing leaves, dying back from tips and scattered through a paddock.

Plant

- Lower leaves affected in young crops.
- Yellow-tan oval spots or lesions on leaves that become tan-brown in their centre with a yellow edge as lesions grow.
- Lesions near leaf tips cause leaf yellowing and withering.
- Look for small black fruiting bodies on stubble which have short, black hair-like projections and feel rough to touch. [25]

What else could it be?

Condition	Similarities	Differences
Septoria nodorum blotch	Tan blotches with yellow margins	Oval to irregular blotches. Tiny brown fruiting bodies in blotches, however these may not be evident to the naked eye. Frequently attacks heads and glumes.
Septoria tritici blotch	Tan blotches often without yellow margins	Blotches irregular, often interveinal, not oval. Tiny black fruiting bodies in blotches, typically visible to the naked eye.

See 'Disease diagnosis' section for diagnosis assistance that is available through DDLS - Plant pathology services.

MORE INFORMATION

Yellow spot,

Septoria nodorum blotch

Septoria tritici blotch.

25 Beard C. (2016). Yellow spot of wheat. DAFWA https://www.agric.wa.gov.au/grains-research-development/managing-yellow-spot-and-septoria-nodorum-blotch-wheat?nopaging=1

9.3.3 Varietal resistance or tolerance

Most triticale cultivars have moderate resistance to yellow spot (Table 5). Though triticale has moderate resistance to yellow spot, it can carryover the disease into following years. [26]

Photo 6: *Triticale variety disease guide for yellow leaf spot.*

Variety	Yellow leaf spot	Septoria tritici
Astute⚗	MRMS	-
Berkshire⚗	MR	RMR
Bison⚗	MR	MR
Canobolas⚗	MR	RMR
Chopper⚗	MR	RMR
Endeavour⚗	MR	R
Fusion⚗	MRMS	R
Goanna	MR	R
KM10	MRMS	MR
Rufus	MR	RMR
Tahara	MR	RMR
Tobruk⚗	MR	R
Tuckerbox	MR	RMR
Yowie	MR	RMR

Maturity: E = early, M = mid season, L = late, VL = very late Height: M = medium, T = tall Colour: W = white, Br = brown Disease resistance order from best to worst: R > RMR > MR > MRMS > MS > MSS > S > SVS > VS. p = provisional ratings - treat with caution. R = resistant, M = moderately, S = susceptible , V = very. # Varieties marked may be more susceptible if alternative strains are present.

Source: Agriculture Victoria

9.3.4 Conditions favouring development

Primary infection of leaf spot diseases is from infected wheat stubble. The fungi that cause leaf spot diseases survive from one season to the next as fruiting bodies on wheat stubble (pseudothecia or pycnidia) or as mycelium in living, volunteer plants. Yellow spot pseudothecia on wheat stubble appear as black raised specks and feel like braille dots when rubbed between the thumb and index finger.

With the onset of winter rains, the over-summering fruiting bodies on stubble release ascospores. Ascospores of septoria nodorum blotch and septoria tritici blotch are readily airborne and result in wide dispersal (over kilometres) while those of yellow spot are larger in size and are dispersed over shorter distances (over metres). Once wheat plants are infected, secondary disease spread occurs — conidia are produced from the leaf infections and these spores are then water dispersed or wind blown through the crop canopy. During the growing season, several cycles of both primary and secondary infection can occur.

DAFWA research has found that the timing of yellow spot spore maturation on stubble differs at different locations in the wheat belt. The release of spores from the fruiting bodies on the stubble is dependent on temperature and rainfall conditions. The wetter, cooler conditions on the south coast for example (around Albany) favour the release of spores before wheat crops are sown or have emerged. On the other hand, the temperature and moisture conditions at Northam and Eradu favour ascospore development from May through to September which coincides with the crop growing season. This provides some explanation why yellow spot is usually more prevalent in the northern agricultural regions compared with the southern agricultural regions. [27]

MORE INFORMATION

Is yellow spot affected by location?

26 Triticale agronomy. (2004). Online farm trials. http://www.farmtrials.com.au/trial/13801

27 Beard C, Jayasena K, Thomas G, Galloway J. (2016). Managing yellow spot and septoria nodorum blotch in wheat. https://www.agric.wa.gov.au/grains-research-development/managing-yellow-spot-and-septoria-nodorum-blotch-wheat?page=0%2C2

Double wheat cropping

As they are stubble-borne, these diseases (but particularly yellow spot) will be most serious in continuous wheat cropping under stubble retention systems. Varieties rated as susceptible to these diseases are particularly vulnerable to infection when sown on wheat stubble and in the absence of fungicide they can sustain significant yield losses.

The fungi that cause these diseases survive on wheat stubble very well for six months between continuous wheat crops but relatively poorly after 18 months, such as wheat grown in one-year rotation with other crops or pasture. Use crop rotation to reduce risk from these stubble-borne diseases.

Weather

While rotation and variety will influence individual crop risk, risk of disease outbreaks that will significantly reduce yield is influenced by rainfall (in autumn, winter and spring). The causal pathogens of the various leaf spot diseases have different environmental conditions that are conducive to disease spread.

For yellow spot, primary infection of wheat leaves (from stubble) requires at least six hours of leaf wetness with temperatures of 15–28°C and periods of dew. Secondary infection (leaf to leaf) is favoured by leaf wetness (dew, fog or rain), high relative humidity and temperatures above10°C.

Septoria nodorum blotch development is favoured by warm weather (such as 20–25°C) in association with heavy and frequent rain; infection depends on leaves remaining wet for more than six hours.

Analysis of rainfall information collected at experimental sites between 1997 and 2004 has demonstrated that an economic response to fungicide (in terms of disease impacts) is more likely when the crop receives approximately 100 mm rainfall or more in the eight weeks following flag leaf emergence. The likelihood of meeting this criterion is increased for:

- early sown crops, as canopy development is complete by late winter (early flag leaf emergence exposes leaf to more disease)
- high rainfall areas or years of above average seasonal rainfall.

Nutritional deficiencies

Research by DAFWA has shown that crops that are deficient in nitrogen and/or potassium are more vulnerable to infection by these diseases.

9.3.5 Managing leaf spot

For the most effective control, an integrated disease management approach is required.

- Use crop rotation to reduce risk from these stubble-borne diseases.
- Avoid very susceptible or susceptible varieties. Favour moderately resistant-moderately susceptible varieties. See the latest wheat variety information for disease ratings.
- Ensure crop has adequate nutrition (particularly nitrogen and potassium).

Fungicides

No seed treatments or in-furrow fungicides are registered for control of yellow spot or septoria nodorum blotch but a few are registered for suppression. Some seed treatments can partially control septoria tritici blotch but are generally not used in this context. For more information see the Registered seed dressing and in-furrow fungicides page.

For wheat grown in rotation, foliar fungicide is more likely to be economic when applied:

- at or around flag leaf emergence (Z39)

- in crops having good yield potential
- where there is evidence of increasing leaf spot intensity down the canopy
- when there are good prospects of finishing rains (approximately 100 mm in the two months after flag leaf emergence).

For wheat after wheat, when there is high disease pressure prior to stem elongation, it may be economic to apply fungicide at or prior to early stem elongation (Z31, first node) particularly in medium to high rainfall areas. A second spray may be required at or after flag leaf emergence based on the above considerations.

Presence of other foliar diseases will enhance returns from fungicide application and direct fungicide choice. Strategies for control of rust diseases with fungicide can vary in important aspects of timing of application.

Use higher rates of fungicide for longer duration of protection, for example, when seasonal conditions favouring infection are likely to persist, for highly susceptible varieties or in long season environments.

Rate and therefore cost should be tuned to crop yield potential; Use a high rate for crops with high yield potential. Refer to product labels.

Late onset of disease (particularly with septoria nodorum blotch - see glume blotch below), may warrant a spray prior to flowering (for example, 50% heads emerged: Z55), particularly in long season environments.

Late spraying is sub-optimal and spraying after crop flowering finishes is generally not economic but further research is being done on this.

Information on which foliar fungicides are registered for leaf spot diseases is available on the Registered foliar fungicides for cereals in WA page. [28]

MORE INFORMATION

Yellow leaf spot – is it worth spraying?

Disease diagnosis

It should be noted that a variety of factors can cause spotting on wheat leaves and the cause is not always a fungal pathogen. For confirmation on disease diagnosis, send 25 infected stems to DDLS - Plant pathology services, Department of Agriculture and Food, Western Australia, Locked Bag 4, Bentley Delivery Centre WA 6983 or call +61 (0)8 9368 3721. This is a chargeable service.

Reporting disease

Please report disease finds to PestFax for the benefit of other growers and the WA wheat industry. You can report disease finds directly online at the PestFax map or otherwise contact the PestFax editor via the PestFax page. PestFax is a free weekly newsletter during the growing season providing information on broadacre disease and pest reports in the WA grainbelt. [29]

9.4 Take-all

Key points:

- Take-all is a fungal disease of the roots of cereals.
- Like cereal rye, Triticale has good resistance to take-all. [30] It is slightly less susceptible to take-all than wheat; early sowing increases the risk. [31]
- In early field experiments conducted over six years with a wide range of Take-all disease severities, triticale was intermediate in resistance to *Gaeumannomyces graminis* (Take-all) between wheat (susceptible) and rye (resistant). [32]

28 Beard C, Jayasena K, Thomas G, Galloway J. (2016). Managing yellow spot and septoria nodorum blotch in wheat. https://www.agric.wa.gov.au/grains-research-development/managing-yellow-spot-and-septoria-nodorum-blotch-wheat?page=0%2C2

29 Beard C, Jayasena K, Thomas G, Galloway J. (2016). Managing yellow spot and septoria nodorum blotch in wheat. https://www.agric.wa.gov.au/grains-research-development/managing-yellow-spot-and-septoria-nodorum-blotch-wheat?page=0%2C2

30 Wallwork, H. (1989). Screening for resistance to take-all in wheat, triticale and wheat-triticale hybrid lines. *Euphytica*, *40*(1–2), 103–109.

31 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

32 Hollins, T. W., Scott, P. R., & Gregory, R. S. (1986). The relative resistance of wheat, rye and triticale to take-all caused by Gaeumannomyces graminis. *Plant pathology*, *35*(1), 93–100.

- Though triticale is less susceptible to take-all than wheat, it can still carryover the disease into following years. [33]
- The fungi responsible are *Gaeumannomyces graminis var. tritici* (Ggt) and *Gaeumannomyces graminis var. avenae* (Gga).
- Grass free pastures and break crops minimise *G. graminis* survival, e.g. pulses and canola.
- Monitor rainfall patterns and adjust sowing times where possible.
- Control weeds during late summer and early autumn.
- Ammonium based nitrogenous fertilisers decrease take-all incidence through improved crop nutrition.
- In severe take-all outbreaks, grass free cropping may be a management strategy.

In Western Australia Take-all is caused by two variations of the *Gaeumannomyces graminis* fungus; *G. graminis* var. *tritici* (Ggt) and *G. graminis* var. *avenae* (Gga) and is most severe in the high rainfall areas of the agricultural region (i.e. southern cropping regions and areas closer to the coast). Control of take-all is predominantly cultural and relies on practices which minimise carry-over of the disease from one cereal crop to the next. [34]

9.4.1 Symptoms

Initial indications of take-all in a crop are the appearance of indistinct patches of poor growth in the crop; these may be a few metres across up to significant areas of crop. Closer inspection of individual plants will indicate discolouration of the crown, roots and stem base. Blackening of the centre of the roots (stele) is symptomatic of an early take-all infection. Severely infected plants will have a blackened crown and stem base and be easy to pull from the soil with no attached root system. Any remaining roots are brittle and break off with a 'square end'.

The appearance of white-heads later in the season is another indicator of a take-all (although frost and micronutrient deficiencies can also cause white-heads), with severe infections causing the crop to hay-off early. Infected plants will produce pinched grain, with severe infections yielding little harvestable seed in the head (hence 'take-all') and in some cases infected areas may not be worth harvesting. [35]

What to look for

Paddock

- Patches (up to several metres in diameter and with indistinct and irregular edges) of white coloured tillers and heads containing shrivelled or no grain (Photo 7).
- Affected plants can be individuals scattered among healthy plants or entire populations of plants over a large area.

33 Triticale agronomy. (2004). Online farm trials. http://www.farmtrials.com.au/trial/13801

34 Soilquality.org. (2016). Take-all Disease – WA. http://www.soilquality.org.au/factsheets/take-all-disease

35 Soilquality.org. (2016). Take-all Disease – WA. http://www.soilquality.org.au/factsheets/take-all-disease

Photo 7: *Patches with irregular edges of white coloured tillers and heads containing shriveled or no grain.*

Source: DAFWA

Plant

- Control First obvious signs of infection are seen after flowering with the development of white heads.
- Roots of affected plants are blackened and brittle and break easily and are black to the core not just on outer surface (Photo 8).
- Severely affected plants can also have blackened crowns and lower stems. [36]

36 DAFWA. (2015). Diagnosing take-all in cereals. https://www.agric.wa.gov.au/mycrop/diagnosing-take-all-cereals

Photo 8: *Roots of affected plants are blackened, brittle and break easily, and are black to the core, not just on the outer surface (left). Severely affected plants can have blackened crowns and lower stems (right).*

Source: DAFWA

9.4.2 Conditions favouring development

Gaeumannomyces graminis survives the Australian summer in the residue of the previous season's grass host (Figure 2). The arrival of cooler temperatures and rainfall in the autumn encourages the fungus into action. The fungus infects the roots of the emerging crop during this period.

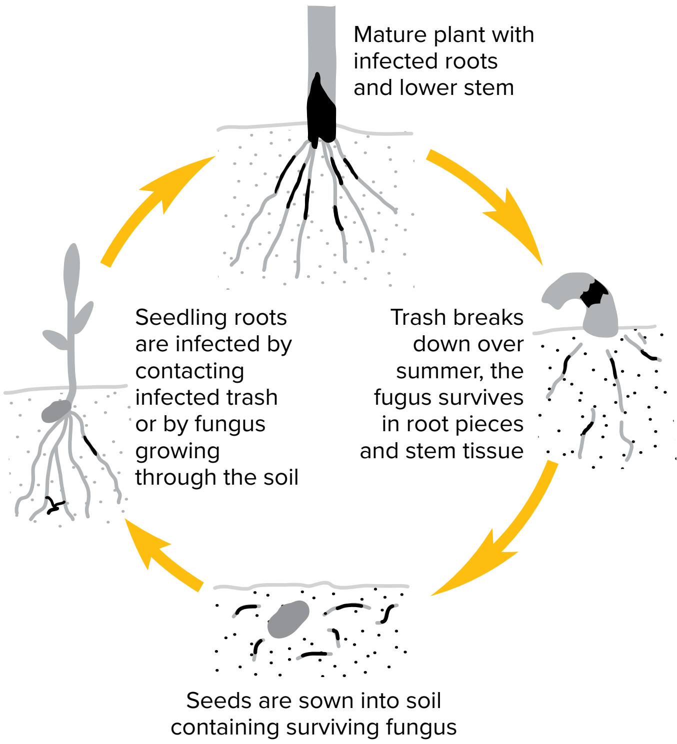


Figure 2: *Common life cycle of the take-all fungus in Western Australian cropping regions (adapted from MacNish, 2005).*

Source: Soilquality.org

Higher rainfall in winter is likely to increase take-all disease pressure. For this reason, the southern regions of Western Australia and those closer to the coast are most likely to suffer yield loss in cereal crops due to take-all (Figure 3). While lower soil moisture will decrease the chance of a severe outbreak of take-all, plants that are already infected will find it difficult to cope due to water stress.

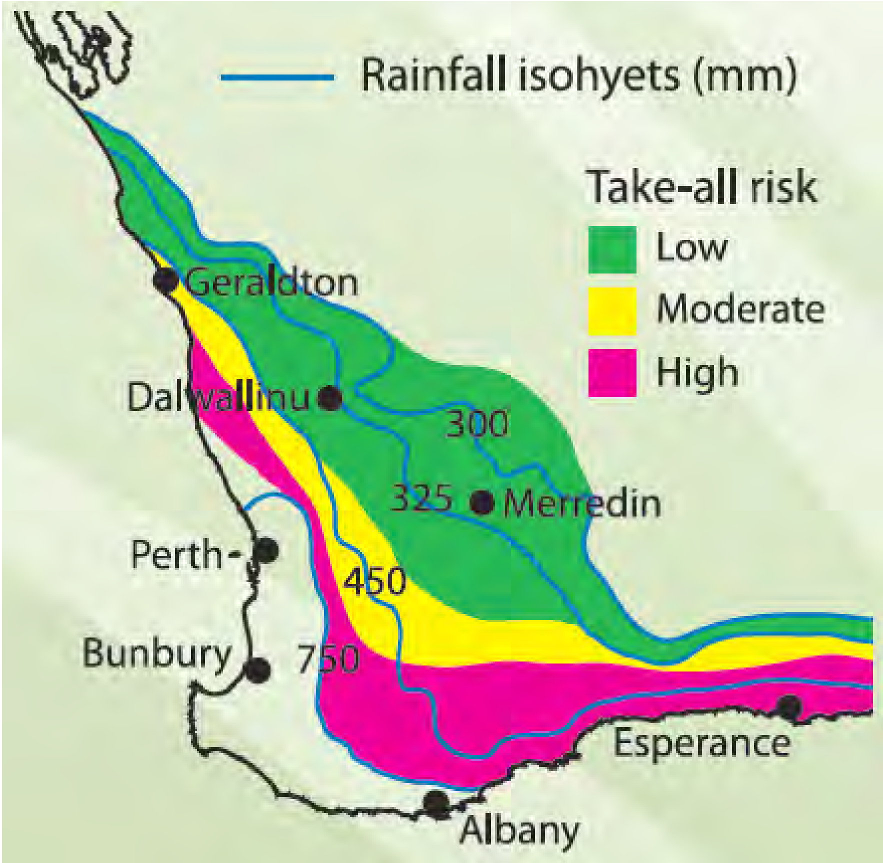


Figure 3: *Western Australian cropping regions most susceptible to take-all infection.*

Source: MacNish, 2005 in Soilquality.org

Soil at field capacity (fully wet) encourages early season infection of seedlings by both *G. graminis* var. *tritici* and *G. graminis* var. *avenae*. Greatest yield loss occurs on infected plants when moisture is limiting post-anthesis.

Hosts

All annual grasses can be infected by *G. graminis*, although some species are more susceptible than others. While wheat, barley and triticale are the most susceptible crops to take-all, barley grass is also an effective host to the disease. Oats are the only cereal crop to offer resistance, although evidence of *G. graminis* strains capable of causing yield loss has been reported in areas where continual oat cropping occurs. Brome grass, silver grass and ryegrass are all viable host species for take-all. All non-cereal crops (e.g. lupins, canola and clover) are non-hosts to take-all. [37]

9.4.3 Managing take-all

Key points:

- By far the most effective method of reducing take-all is to remove grasses in the year before the crop with a grass-free pasture or 'break' crop.
- Seed, fertiliser or in-furrow applied fungicides are registered for take-all control.

37 Soilquality.org. (2016). Take-all Disease – WA. http://www.soilquality.org.au/factsheets/take-all-disease

- Acidifying fertilisers can slightly reduce disease severity (take-all severity may increase following liming).
- Control volunteer grasses and cereals.
- Delay sowing following the opening rains by implementing a short chemical fallow. [38]

The most effective management strategy for take-all is to deny the fungus the ability to survive in the paddock, through the elimination of hosts. This is most effectively done through the use of a non-cereal break crop (lupin, canola, field peas, faba bean, chickpea, sorghum) and effective grass weed control during autumn. Pastures containing low levels of grass species will also have reduced take-all carryover the following season. Where minimum tillage is practiced the time taken for residues to breakdown is increased allowing the disease to stay viable for longer. The use of break crops and activities to hasten residue breakdown may be beneficial. While burning does decrease the amount of surface residue infected with the fungus, it is generally not hot enough to affect the infected material below ground.

Fungicides, applied as either fertiliser or seed treatments, are registered but are generally only economically viable where severe outbreaks have occurred. Registered fungicides provide useful protection in low to medium disease risk paddocks. In many cases it is more practical to sow non-cereal crops or pasture to reduce take-all carryover.

Competition from other soil organisms decreases the survival of *G. graminis* in the soil. Summer rains or an early break in the season allows for such conditions. The effect of this can be negated by poor weed control during this period.

This has a double effect;

1. cereal weeds become infected, thus enabling *G. graminis* to survive until crop establishment, and,
2. rapid drying of the topsoil due to weeds decreases the survival of competitive soil organisms, therefore slowing *G. graminis* decline.

Take-all decline

Take-all decline is the apparent waning of take-all incidence following many years of continuous cereal cropping. This has been attributed to the 'build-up' of antagonistic micro-organisms in the soil. Although this process may be possible, the economic losses incurred during the 'build-up' appear to be unacceptable. There have, however, been examples of a reduction in take-all incidence due to gradual acidification of soil; this decline is reversed when lime is applied to increase soil pH. [39]

9.5 Crown rot

Key points:

- Triticale is susceptible to crown rot. [40]
- Fusarium species are responsible for causing two distinctly different diseases in winter cereal crops—crown rot and Fusarium head blight.
- Crown rot survives on infected stubble, from where it is passed onto the following crop.
- Use non host crops (pulse, oilseeds and broad leaf pasture species) in rotation sequences to reduce inoculum levels.
- Control grass weed hosts to reduce opportunities for Fusarium to survive fallow or non-host rotations.
- Sow varieties with partial resistance or improved tolerance where available.

38 DAFWA. (2015). Diagnosing Take-all in cereals. https://www.agric.wa.gov.au/mycrop/diagnosing-take-all-cereals

39 Soilquality.org. (2016). Take-all Disease – NSW. http://www.soilquality.org.au/factsheets/take-all-disease-nsw

40 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

Information concerning the resistances of triticale varieties to *Fusarium* diseases is very limited. For crown rot (*Fusarium psuedograminearum)* most work has been completed in wheat but data from 2007 included one triticale (Everest). Inoculation with the crown rot fungus caused the greatest reduction in yield in durum wheat (average of 58%) with less but similar reduction in five wheat varieties (25%) and one triticale (23%). Within the wheat varieties the reductions were in a 10% range and it is likely that a similar position would occur within triticale varieties. This emphasises the importance of crop rotational strategy (use of disease break crops such as canola/mustard) within the cropping system. [41]

There are two types of fusarium disease that affect cereal crops, Fusarium head blight (FHB) and crown rot (CR).

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. [42]

A survey of WA paddocks from 2010–2013 found little incidence of crown rot. However, this study demonstrated that even with low levels of disease present, rotation with break crops can manage inoculum levels of crown rot. Pastures did not offer a break to the cereal, suggesting that unmanaged pastures can contribute to the problem of crown rot. Inoculum levels are likely to build up when continuous cereals are grown; in fertile soils; and in dry summers. [43]

The prevalence of crown rot increased in WA in 2014 with 30–50% of wheat paddocks around Merredin reporting impacts (Figure 4). The increased expression in 2014 was likely the result of intensive cereal production, in combination with 2013 and 2014 seasonal factors. In 2013, wet spring conditions probably contributed to disease build but with few white heads due to the soft finish. In 2014, the drier spring in many areas resulted in a high expression of white head formation. [44]

41 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

42 GRDC. (2016). Tips and Tactics: Crown rot in winter cereals – Southern region.

43 Lawes R, Harries M, Huberli D, Shea G, Miyan S. (2015). Rhizoctonia and crown rot status of western Australian paddocks can be managed with crop rotation. http://www.giwa.org.au/pdfs/CR_2015/SORT/EOI_67_Lawes_Roger_Rhizoctonia_and_Crown_Rot_status_Paper_CU2015_.pdf

44 DAFWA. (2014). 2014 increase in crown rot in wheatbelt. https://www.agric.wa.gov.au/news/media-releases/2014-increase-crown-rot-wheatbelt

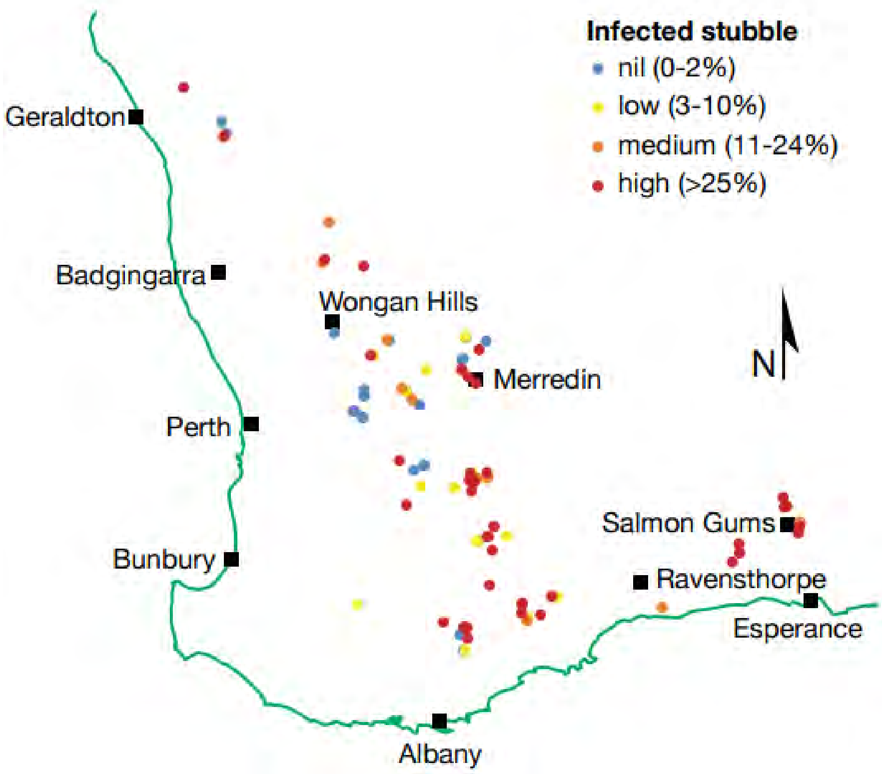


Figure 4: *Crown rot incidence in Western Australia based on two year stubble survey (2013/2014).*

Source: GRDC

Both FHB and CR become apparent after flowering, however head blight requires prolonged wet weather during flowering and grain fill whilst crown rot expresses as whiteheads following periods of moisture and/or heat stress. Crown rot can sometimes be first seen in patches or in wheel tracks, but is often not obvious until after heading. Dead heads containing shrivelled or no grain, called 'whiteheads' appear, although it is important to note that yield loss can occur even without the formation of whiteheads.

9.5.1 Damage caused by crown rot

The presence of crown rot within the plant stem limits water movement, which can result in premature death of the tiller and the presence of white (dead) heads (Photo 9). Crown rot survives from one season to the next on infected stubble, from where it is passed onto the following crop. The impact of a bad crown rot season can make or break a crop, with bread wheat yield losses of up to 55 per cent possible at high inoculum levels, and losses in durum up to 90 per cent.

Photo 9: *Scattered whiteheads leading to large yield losses in cereal crops.*

Source: DAFWA

9.5.2 Symptoms

If the leaf bases are removed from the crowns of diseased plants, a honey-brown to dark-brown discolouration will be seen. In moist weather, a pink-purple fungal growth forms inside the lower leaf sheaths and on the lower nodes.

Infection is characterised by a light honey-brown to dark brown discolouration of the base of infected tillers, while major yield loss from the production of whiteheads is related to moisture stress post-flowering.

The infection of plants with crown rot occurs at the base of the plant and spreads up the stem during the growing season. The onset of crown rot is often not obvious until after heading, when whiteheads appear with the onset of water stress. Plants infected with crown rot display a number of symptoms, including:

- Brown tiller bases, often extending up 2 – 4 nodes (Photo 10). This is the most reliable indicator of crown rot, with browning often becoming more pronounced from mid to late grain filling through to harvest.
- Whitehead formation, particularly in seasons with a wet start and dry finish (Photo 11). These are usually scattered throughout the crop, and do not appear in distinct patches. These may first appear in wheel tracks where crop-available moisture is more limited.
- A cottony fungal growth that may be found around the inside of tillers, and a pinkish fungal growth that may form on the lower nodes, especially during moist weather (Photo 12).
- Pinched grain at harvest. [45]

45 Soilquality.org. (2016). Crown rot – Qld. http://www.soilquality.org.au/factsheets/crown-rot-queensland

Photo 10: *Honey-brown discolouration of stem bases.*

Source: DAFWA

Photo 11: *Scattered single tillers and white heads.*

Source: DAFWA

Photo 12: *Pink discolouration often forms around or in the crown or under leaf sheaths.*

Source: DAFWA

MORE INFORMATION

Diagnosing crown rot of cereals

Soil testing

In addition to visual symptoms, the DNA-based soil test ('PreDicta B™') can be used to assess the level of crown rot in the paddock. Soil samples that include plant residues should be tested early in late summer to allow results to be returned before seeding. This test is particularly useful when sowing susceptible wheat varieties, and for assessing the risk after a non-cereal crop. [46]

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

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

- cereal cyst nematode (CCN)
- take-all (*Gaeumannomyces graminis* var. *tritici* (Ggt) and *G. graminis* var. *avenae* (Gga))
- rhizoctonia barepatch (*Rhizoctonia solani* AG8)
- crown rot (*Fusarium pseudograminearum*) *Note that oats are not very susceptible to crown rot – but does host it.
- root lesion nematode (*Pratylenchus neglectus* and *P. thornei*)
- stem nematode (*Ditylenchus dipsaci*)

46 Soilquality.org. (2016). Crown rot – Qld. http://www.soilquality.org.au/factsheets/crown-rot-queensland

MORE INFORMATION

PIR SA Predicta B website

VIDEOS

WATCH: GRDC Updates: Improving PreDicta B.

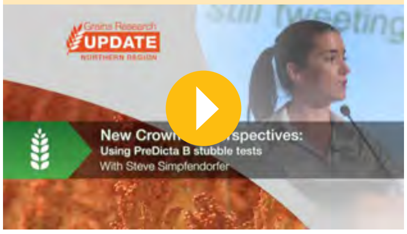


Photo 13: *Sampling for PreDicta B*

Source: GRDC

PreDicta B samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program. PreDicta B is not intended for in-crop diagnosis. That is best achieved by sending samples of affected plants to your local plant pathology laboratory.

9.5.3 Fusarium head blight (FHB) symptoms

FHB is an infection of the head rather than root or crown as with CR. In wheat, FHB appears as premature bleaching of spikelets within a head. Frequently only part of the head (usually the upper half) is affected (Photo 14). Salmon pink to orange spore masses (sporodochia) at the bases of infected spikelets can also be apparent during prolonged warm, humid weather. Infected wheat grains have a chalky white appearance and are usually shrivelled and lightweight; they may sometimes have pink staining too. In barley, infected spikelets have a brown or a water-soaked appearance, rather than bleaching. The grains have an orange or black encrustation on their surfaces rather than being chalky white.

Photo 14: *Heads are partly or fully bleached.*

Source: DAFWA

9.5.4 Conditions favouring development

FHB is a fungal disease that affects cereals. It survives from one season to the next in the stubble remains of infected plants. The disease is more common on heavy clay soils.

Infection is favoured by high soil moisture in the two months after planting. Drought stress during elongation and flowering will lead to the production of 'deadheads' or 'whiteheads' in the crop. These heads contain pinched seed or no seed at all.

The effects of crown rot on yield tend to be most severe when there are good crop conditions in the first part of the season followed by a dry finish. This is because the moist conditions at the beginning of the season enable the fungus to grow from infected stubble to an adjacent seedling, while the dry conditions during flowering and grain filling cause moisture stress, allowing rapid growth of the pathogen within the plant. A wet finish to the season can reduce the damage caused by crown rot, but will not prevent yield loss in all cases. [47]

Soil water is by far the biggest factor in the impact of crown rot on profitability. The effect of moisture on crown rot yield losses is huge.

Cultivation can also have a huge impact. 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. So by cultivating soil, growers are actually helping to spread the crown rot inoculum to next year's crop. The best thing a grower can do with infected stubble is leave it alone. [48]

9.5.5 Managing crown rot

Key points:

- Varietal resistance and tolerance to crown rot is limited. Most wheat varieties grown in WA are either susceptible or very susceptible to crown rot
- There are no fungicide options for the control of crown rot.
- Rotate crops. This is the most important management option. A grass-free break from winter cereals is the best way to lower crown rot inoculum levels.
- Observe. Check plants for browning at the base of infected tillers as this is the most reliable indicator of crown rot. Don't rely solely on whiteheads as an indicator (Figure 5).
- Test. A pre-sowing PreDicta B™ soil test will identify paddocks at risk of crown rot.
- Sow winter cereals, into paddocks where the risk is lowest.
- Choosing more resistant crop varieties can help but still need to be combined with effective management.
- Keeping crown rot inoculum at low levels is the most effective way to reduce yield loss from this disease. [49]

47 Soilquality.org. (2016). Crown rot – Qld. http://www.soilquality.org.au/factsheets/crown-rot-queensland

48 Dixon T. (2013). Balanacing crown rot and nematodes in wehat. 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

49 GRDC. (2016). Tips and Tactics: Crown rot in winter cereals – Western region. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/tt-crownrotwintercereals

Figure 5: *The GRDC's "Stop the crown rot" campaign.*

Source: GRDC

The disease may be controlled through planting partially resistant varieties or crop rotation. If the disease is severe, rotation to a non-susceptible crop for at least two and preferably three years is recommended. A winter crop such as chickpea, oats or any summer crop may be used as a disease-free rotation crop.

Variety selection

Where growers are aware their paddocks are infected with crown rot, resistant varieties can be used to limit yield loses.

Growers need to be aware of the levels of crown rot disease in their paddocks, as even the most resistant crops can suffer yield loss under high levels of the disease. At intermediate levels, the grower can make a calculated risk of returns versus yield loss by growing only resistant varieties. However, where high levels of disease are present even resistant varieties may be affected, and a break crop may be required.

VIDEOS

WATCH: [GRDC Updates: Crown rot tolerance in new cereal varieties.]

If a cereal must be sown but there is a risk of yield loss from crown rot:

- *Select a cereal type which will have the lowest yield loss. Barley is the first choice, followed by bread wheat and triticale. Avoid durum;*
- *Match nitrogen application to stored soil moisture and potential yield;*
- *Limit nitrogen application prior to and at sowing to avoid excessive early crop growth;*
- *Ensure zinc nutrition is adequate; and*
- *Sow on the inter-row if this option is available.*

Agronomist's view

Rotation Management

Because crown rot survives from one season to the next on infected stubble, the use of break crops can give stubble a chance to decompose and thus reduce soil inoculum levels. The use of break crops with dense canopies, such as canola and sorghum, can be particularly effective, as these help to maintain a moist soil surface, encouraging the breakdown of cereal residues.

The number or break crops required to sufficiently reduce crown rot levels will vary, depending on rainfall in the break year. In dry years, when residue breakdown is slower, a two-year break crop may be required to reduce crown rot to acceptable levels. In wetter seasons a one-year break may be sufficient.

It should be noted that incorporating plant residues into the soil by cultivation during the break period can increase the rate of residue decay. However, cultivation also spreads infected residue, which may increase plant infection rates in following crops – thus counteracting any benefits from increased residue breakdown.

Baling, grazing and/or burning crop residues are also not effective solutions for the removal of crown rot. The majority of the crown rot inoculum is below ground and in the bottom 7 cm of the stem. Thus the crown rot fungus can still survive in below ground tissue even if above ground material is removed.

MORE INFORMATION

Rhizoctonia and crown rot status of western Australian paddocks can be managed with crop rotation.

Crop Management

Stressed plants are most susceptible to the effects of crown rot. Thus the use of management practices to optimise soil water and ensure good crop nutrition can help reduce the impacts of crown rot. Effective strategies can include:

- Reducing moisture stress in plants through good fallow management and avoiding excessively high sowing rates.
- Matching nitrogen fertiliser inputs to available soil water to avoid excessive early crop growth.
- Ensuring good crop nutrition. Zinc nutrition can be particularly important as the expression of whiteheads can be more severe in zinc-deficient crops.

Managing stubble

- Inoculum will be more concentrated below ground and in the bottom 7 cm of the stem (Figure 6).
- Stubble management practices such as cultivating, spreading and slashing through cultivation can increase the rate of stubble decomposition but can also spread the infected residues across the paddock.
- Where there is no stubble moisture or adequate time to accelerate stubble breakdown, these practices can increase infection rates in the next winter cereal crop.
- Grazing stubble can also spread inoculum.

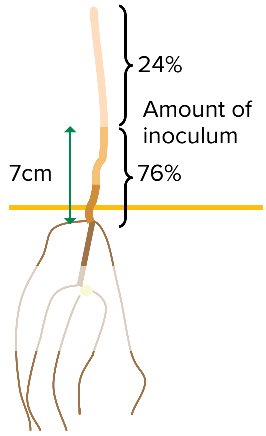


Figure 6: *Crown rot distribution in infected cereal stubble.*

Source: GRDC

IN FOCUS

How to manage crown rot – research update

Key points:

- Impact of crown rot on yield and quality is a balance between inoculum levels and soil water
- The balance is heavily tipped towards soil water yet most management strategies tend to focus solely on combating inoculum, sometimes to the detriment of soil water
- Cultivation (even shallow) distributes infected residue more evenly across paddocks and into the infection zones below ground for crown rot, increasing the likelihood of infection.
- Some of the newer varieties appear promising in that they provide improved tolerance to crown rot
- PreDicta B® is a good technique for identifying the level of risk for crown rot (and other soil-borne pathogens) prior to sowing within paddocks. However, this requires a dedicated sampling strategy and is not a simple add on to a soil nutrition test.

Crop rotation

The most effective way to reduce crown rot inoculum is to include non-susceptible crops in the rotation sequence. The crown rot fungus can survive for two to three years in stubble and soil. Growing a non-host crop for at least two seasons is recommended to reduce inoculum levels. This allows time for decomposition of winter cereal residues that host the crown rot fungus. Stubble decomposition varies with the type of break crop grown – their canopy density and rate of the canopy closure as well as row spacing, the amount of soil water they use and seasonal rainfall.

Cultivation

Growers may cultivate their stubble for a range of reasons e.g. to reduce trash load prior to sowing. However, the effect of cultivation on crown rot is complex as it potentially impacts on all three phases of the disease cycle.

Survival: Stubble decomposition is a microbial process driven by temperature and moisture. Cultivating stubble in theory increases the rate of decomposition as it reduces particle size of stubble, buries these particles in the soil where microbial activity is greater and the soil environment maintains more optimal moisture and temperature conditions compared to the soil surface or above ground. However, cultivation also dries out the soil in the cultivation layer, which immediately limits the potential for decomposition of the incorporated stubble. Decomposition of cereal stubbles is a *very slow* process that requires adequate moisture for an extended period of time to occur completely. A summer fallow (even if extremely wet and stubble has been cultivated) is **not** long enough!

*Infection: T*he majority of infection sites with crown rot are below ground and physical contact between an infected piece of residue and these plant parts is required to initiate infection. Cultivation of winter cereal stubble harbouring the crown rot fungus effectively breaks the inoculum into smaller pieces and spreads them more evenly through the cultivation layer across the paddock. Consequently, the crown rot fungus has been given a much greater chance of coming into contact with the major infection sites below ground as the next winter cereal crop germinates and develops. In a no-till system the crown rot fungus becomes confined to the previous cereal rows and is more reliant on infection through the outer leaf sheathes at the soil surface. This is why inter-row sowing with GPS guidance has been shown to provide around a 50% reduction in the number of plants infected with crown rot when used in a no-till cropping system. Cultivation or harrowing negates the option of inter-row sowing as a crown rot management strategy. [50] In the Western region inter-row sowing using accurate ± 2 cm differential GPS autosteer has been shown to decrease the number of infected plants by about 50%, resulting in a 5% to 10% yield advantage in the presence of crown rot. [51]

Expression: extensive research has shown that cultivation dries out the soil to the depth of cultivation and reduces the water infiltration rate due to the loss of structure (macropores etc). The lack of cereal stubble cover can also increase soil evaporation. With poorer infiltration and higher evaporation, fallow efficiency is reduced for cultivated systems compared to a no-till stubble retention system. Greater moisture availability has the potential to provide buffering against crown rot expression late in the season. Like crown rot management and all farming practices, cultivation is a balancing act between perceived benefits and costs.

Stubble burning

Burning removes the above ground portion of crown rot inoculum but the fungus will still survive in infected crown tissue below ground so it is **not** a 'quick fix' for high inoculum situations. Removal of stubble through burning will increase evaporation from the soil surface and impact on fallow efficiency. A 'cooler' autumn burn is therefore preferable to an earlier 'hotter' burn as it minimises the negative impacts on soil moisture storage whilst still reducing inoculum levels.

Reduce water loss

Inoculum level is important in limiting the potential for yield loss from crown rot but the overriding factor dictating the extent of yield loss is moisture/ temperature stress during grain-fill. Any management strategy that limits storage of soil water or creates constraints that reduce the ability of roots to access this water will increase the probability and/or severity of moisture stress during grain-fill and exacerbate the impact of crown rot.

50 Simpfendorfer S. (2015). GRDC Update Paper: Crown rot – an update on latest research. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Crown-rot-an-update-on-latest-research

51 GRDC. (2016). Tips and Tactics: Crown rot in winter cereals – Western region. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/tt-crownrotwintercereals

Grass weed management

Grass weeds should be controlled in fallow periods and in-crop, especially in break crops, as they host the crown rot fungus and can also significantly reduce soil moisture storage. In pasture situations grasses need to be cleaned out well in advance of a following cereal crop as they serve as a host for the crown rot fungus.

Row placement

In a no-till system the crown rot fungus becomes confined to the previous cereal rows and is more reliant on infection through the outer leaf sheathes at the soil surface. This is why inter-row sowing with GPS guidance has been shown to provide around a 50% reduction in the number of plants infected with crown rot when used in a no-till cropping system. Further research has also demonstrated the benefits of row placement in combination with crop rotation and the relative placement of break crop rows and winter cereal rows within the sequence to limit disease and maximise yield. Sowing break crops between standing wheat rows which are kept intact then sowing the following wheat crop directly over the row of the previous years break crop ensures four years between wheat rows being sown in the same row space. This substantially reduces the incidence of crown rot in wheat crops, improves establishment of break crops (esp. canola) and chickpeas will benefit from reduced virus incidence in standing wheat stubble.

Soil type

Soil type does not differentially affect the survival or infection phases of crown rot. However, the inherent water holding capacity of each soil type interacts with expression by potentially buffering against moisture stress late in the season. Hence, yield loss can be worse on red soils compared to black soils due to their generally lower water holding capacities. Any other sub-soil constraint e.g. sodicity, salinity or shallower soil depth effectively reduces the level of plant available water which can increase the expression of crown rot.

Cereal crop and variety choice

All winter cereal crops host the crown rot fungus. Yield loss varies between crops and the approximate order of increasing loss is oats, barley, triticale, bread wheat and durum.

However, variety choice is NOT a solution to crown rot with even the best variety still suffering up to 40% yield loss from crown rot under high infection levels and a dry/hot seasonal finish. All current durum varieties are very susceptible to crown rot and should be avoided in medium and high risk situations.

Sowing time

Earlier sowing within the recommended window of a given variety for a region can bring the grain-fill period forward and reduce the probability of moisture and temperature stress during grain-fill. Earlier sowing can increase root length/depth and provide greater access to deeper soil water later in the season, which buffers against crown rot expression. Earlier sowing however can place a crop at risk of frost damage during its most susceptible time. Sowing time is a balancing act between the risk of frost and heat stress. However, when it comes to crown rot, increased disease expression with delayed sowing can have just as big an impact on yield as frost. The big difference is the additional detrimental impact of later sowing on grain size in the presence of crown rot infection.

MORE INFORMATION

Tips and Tactics: Crown rot in winter cereals – Western region.

Understanding crown rot underpins effective management – Southern and Western regions

Interaction with root lesion nematodes

Root lesion nematodes (RLNs) are also a wide spread constraint to wheat production across the region. RLNs feed inside the root systems of susceptible winter cereals creating lesions and reducing lateral branching. This reduced the efficacy of the root system to extract soil water and nutrients which subsequently can exacerbate the expression of crown rot. Varieties with reduced tolerance of *P. thornei* can suffer significantly greater yield loss from crown rot if both of these pathogens are present within a paddock.

How do I know my level of risk for crown rot and RLN?

PreDicta B® is a DNA based soil test which detects levels of a range of cereal pathogens that is commercially available to growers through the South Australian Research and Development Institute (SARDI). Because the crown rot fungus is stubble-borne, normal soil samples are unreliable and disease detection is highly sensitive to the sampling technique used. Follow the specific protocols for how to collect samples for crown rot testing (further paper in these proceedings).

If you are not willing to follow the recommended PreDicta B® sampling strategy then DO NOT assesses disease risk levels prior to sowing. [52]

9.6 Rhizoctonia

Key points:

- Rhizoctonia bare-patch (*R. solani* AG8) is a major problem across WA's cereal growing regions and is estimated to reduce WA state-wide cereal yields by 1% to 5% annually at a cost of $27M in wheat and barley.
- Rhizoctonia is most evident as bare patches in a young crop. Close inspection of infected seedlings shows brown discolouration or rotting of the roots and evidence of 'spear tips'.
- In cereals, oats are most tolerant followed by triticale, wheat and then barley, which is the most intolerant. [53]
- Adequate nutrition during crop emergence gives the crop better chance of 'getting ahead' of the disease.
- Fast growing roots will push past the infected topsoil before *Rhizoctonia* infects the root tip.
- Poor weed management prior to seeding allows *Rhizoctonia solani* to 'prime' itself for infection of the upcoming crop.
- In severe paddock infections cultivation following late summer – early autumn rains can help to reduce infection by the fungus.

Rhizoctonia is a fungal disease affecting a wide range of crops and has become more prevalent throughout Western Australia in recent years, following the introduction of minimum tillage practices. The previous practice of tillage prior to seeding encouraged the breakdown of the fungus in the soil prior to emergence. Minimum tillage practices decrease the rate of organic matter breakdown, thereby providing a habitat for *Rhizoctonia* over summer.

The disease affects most major crops to varying degrees, with barley being most susceptible and oat crops least susceptible. Bare patch and root rot of cereals, and

52 Simpfendorfer S. (2015). GRDC Update Paper: Crown rot – an update on latest research. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Crown-rot-an-update-on-latest-research

53 GRDC. (2008). Rhizoctonia – Fact Sheet.

VIDEOS

WATCH: Over the Fence: Improving soil health helps fight against rhizoctonia.

damping off and hypocotyl rot of oilseed and legumes are all caused by differing strains of *R. solani*. [54]

9.6.1 Symptoms

The characteristic symptom of *Rhizoctonia* is clearly defined bare patches in the crop. The reason these patches are clearly defined relates to the susceptibility of young seedlings, and the placement of the fungus within the soil profile. *Rhizoctonia solani* tends to reside in the upper layers of soil but not in the surface and only infects seedlings through the root tip soon after germination. Older plants have a more developed root epidermis that does not allow the penetration of hyphae into the root. For this reason, once the crop is fully established, plants have either perished due to seedling infection or reasonably healthy. Some yield loss may be associated with plants on the margins of the bare patch. Roots of a plant infected with *R. solani* will typically be shortened with a brown 'spear tip' where they have rotted. Plants within a patch remain stunted with stiff, rolled leaves and can be darker green than those outside the patch. [55]

What to look for

Paddock

- Severely stunted plants occur in patches with a distinct edge between diseased and healthy plants.
- Patches vary in size from less than half a metre to several metres in diameter.
- Patches of uneven growth occur from mid winter when seminal roots have established (Photo 15).

Photo 15: *Patches vary in size from less than a metre to several metres in diameter. Stunted plants occur in patches with a distince edge between diseased and healthy plants.*

Source: DAFWA

54 Soilquality.org. (2016). Rhizoctonia – NSW http://www.soilquality.org.au/factsheets/rhizoctonia-nsw

55 Soilquality.org. (2016). Rhizoctonia – NSW http://www.soilquality.org.au/factsheets/rhizoctonia-nsw

Plant

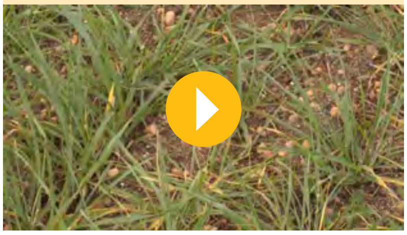
- Affected plants are stunted with stiff, rolled leaves and are sometimes darker green than healthy plants (Photo 16).
- Roots of affected plants are short with characteristic pinched ends: 'spear tips' (Photo 17).

Photo 16: *Affected plants are stunted with stiff, rolled leaves which are sometimes darker than those of healthy plants.*

Source: DAFWA

VIDEOS

WATCH: How to diagnose Rhizoctonia root rot.



MORE INFORMATION

Diagnosing rhizoctonia root rot in cereals

Photo 17: *Roots of affected plants are short with characteristic pinched ends or 'spear tips'.*

Source: DAFWA

9.6.2 Conditions favouring development

Rhizoctonia solani survives best in organic matter just below the surface of an undisturbed soil. The fungus benefits from summer rainfall events by infecting and multiplying on weeds, and has a limited ability to survive on the residue of previous seasons crops. The break of season initiates the development of the fungus in soil, thereby priming itself for infection of germinating seeds. Infection by the pathogen is encouraged by factors that restrict root growth, such as low soil fertility and sulfonylurea herbicides. If there is a delay between the season break and seeding, it is imperative that weeds are controlled to minimise proliferation of the fungus. Good nitrogen nutrition helps to minimise the effects of the disease; bare patches are smaller and less severe.

In general, *Rhizoctonia* is most likely to be a severe problem where the plant is under stress from factors other than the disease, for example, low rainfall or poor nutrition.

Factors Affecting *Rhizoctonia*

There are certain soil conditions that favour *Rhizoctonia* development during and after seeding.

Soil Nutrition

The disease is most common in soils of poor fertility (Department of Agriculture and Food, Western Australia 2006). Crops with access to sufficient nutrients for growth have a better ability to 'get ahead' of *Rhizoctonia* infections.

Soil Disturbance

Rhizoctonia is sensitive to cultivation, with cultivation after rain and before sowing most effective at reducing infection. Disturbing the soil does not allow the fungus to 'prime' itself for infection of the emerging crop.

Soil Moisture

Under moisture stress the crop becomes more susceptible to *R solani* infection and has a decreased ability to get ahead of the disease.

Weeds

Poor weed management following late summer and early autumn rain allows *Rhizoctonia* to infect grass weeds, thereby allowing the fungus to multiply in preparation for the crop.

Herbicides

Sulfonylurea herbicides can sometimes worsen *Rhizoctonia*, and this is attributed to minor herbicidal effects on the crop. [56]

9.6.3 Managing Rhizoctonia

Where reduced tillage is practiced, *Rhizoctonia* bare patch is best controlled through effective management of weeds and maintaining adequate nutrition for the establishing crop. Spraying weeds with a fast acting knock down herbicide will minimise the development of the fungus in the ground prior to seeding, and good nutrition gives the crop a better chance of getting ahead of the disease.

Best tillage practices involve deep cultivation and shallow sowing, with minimal time between each event. In no-till systems the use of modified sowing points that provide some soil disturbance 5–10 cm below the seed can be useful in controlling the disease.

In the past, tillage was the most effective method of reducing the impact of *Rhizoctonia*. The establishment of *R. solani* in the topsoil late in autumn was negated as cultivation broke the network of fungal hyphae. The fungus did not have time to recover before seedling establishment. In severely infected paddocks, cultivation may be an important management strategy.

Currently there are no resistant crop varieties but there are products on the market for *Rhizoctonia*. Consult your local advisor for specific information.

In areas where the disease is known or suspected it is best practice to clean knife points once the seeding is complete, thereby eliminating movement of the fungus from one paddock to the next. In general, maintaining adequate nutrition (especially nitrogen) during crop establishment is the best way to reduce the chance of *R. solani* infection. [57]

IN FOCUS

Integrated disease management options to control rhizoctonia bare-patch in cereals

Key points:

- When sowing to wheat or another cereal in a paddock with a previous history of Rhizoctonia bare-patch, using cultivation below the seed (~10 cm) and a registered fungicide can reduce disease impact.

56 Soilquality.org. (2016). Rhizoctonia – NSW http://www.soilquality.org.au/factsheets/rhizoctonia-nsw

57 Soilquality.org. (2016). Rhizoctonia – NSW http://www.soilquality.org.au/factsheets/rhizoctonia-nsw

- A break crop of canola or a chemical fallow may be useful for reducing Rhizoctonia inoculum in the soil prior to sowing a cereal crop.
- In the near future, new in-furrow fungicide options, that improve the control of Rhizoctonia disease in barley and wheat, may become available to WA farmers.

Research in WA in 2012 aimed to determine the efficacy of the new fungicides to control Rhizoctonia in cereals. Also, the effect of rotation and current management options to control *R. solani* were examined. All test sites had visible patches in cereals the previous year and the pathogen was confirmed to be R. solani (AG8) by PreDicta-B® soil test. Trials were sown by cone-seeder and spayed regularly with foliar fungicide to remove confounding effects of differences in leaf disease.

The results of this research support the current recommendation for management of Rhizoctonia bare-patch. When sowing to wheat or another cereal in a paddock with a high rhizoctonia risk, cultivate below the seed (at least 10 cm) at the time of sowing and use a registered fungicide.

A break crop of canola or chemical fallow, in paddocks with severe Rhizoctonia bare-patch, may reduce Rhizoctonia inoculum levels and reduce disease in the following cereal crop.

In paddocks with Rhizoctonia, barley will exacerbate the disease substantially compared to other crops.

MORE INFORMATION

Integrated disease management options to control rhizoctonia bare-patch in cereals

Rhizoctonia Fact sheet – Western region

9.7 Smut and bunt

Cereal smut and bunt diseases are caused by fungi which parasitise the host plant and produce masses of soot-like spores in the leaves, grains or ears. These fungi are damaging pathogens of cereal crops, reducing yield and quality of harvested grain. In many cases grain receival points have low or zero tolerance of smut contaminated grain. The major Western Australian cereal crops, wheat, barley and oats, are susceptible to a range of smut and bunt diseases. [58]

Triticale is not usually prone to infection from smuts and bunt. However, it is good insurance to apply a seed dressing to the grain when it is being graded. [59]

9.7.1 Bunt or stinking smut

This disease affects mature triticale, durum and wheat ears in which a mass of black-fungal spores replaces the interior of the grain and forms a bunt ball. Infected plants are shorter and have darker green ears and gaping glumes than healthy plants (Photo 18). Bunt is usually only noticed at harvest when bunt balls and fragments are seen in the grain.

58 DAFWA. (2016). Smut and bunt diseases of cereal – biology identification and management. https://www.agric.wa.gov.au/autumn/smut-and-bunt-diseases-cereal-biology-identification-and-management

59 Agriculture Victoria. (2012). Growing Triticale. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

Photo 18: *Common bunt in cereal head showing glumes containing bunt balls.*

Source: DAFWA

If a bunt ball is crushed, a putrid fish-like odour is released. Spores released during harvest contaminate sound grain. The spores germinate with the seed when planted and infect the young seedling. The fungus then grows inside the developing wheat plant, finally replacing each normal grain with a mass of spores.

Managing bunt

- Seed that is sown to provide the following season's wheat seed should be treated with a fungicidal seed dressing.
- Seed obtained from plants grown from untreated seed should be treated with a fungicidal seed dressing before planting.
- All seed should be treated with a fungicidal seed dressing which will control bunt.
- Grain from a crop with bunt should not be used for seed.
- On farms where a crop has been affected by bunt, all wheat seed should be treated with fungicidal seed dressing for at least six years.

These recommendations could be adopted in one of two ways:

1. Treat all wheat seed with a fungicidal seed dressing every second year.
2. Treat a small quantity of seed of each variety with a fungicidal seed dressing every year and use the grain from this as planting seed in the following year. [60]

9.7.2 Loose smut

Triticale is susceptible to loose smut,[61] though it does not usually occur to a degree where control is warranted.

Loose smut is a fungal disease that becomes evident at head emergence. A loose, powdery mass of fungal spores is formed in the head; these spores are readily blown away leaving a bare, ragged stalk (Photo 19).

60 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

61 Matthews P, McCaffery D, Jenkins L. (2016). Winter crop variety sowing guide 2016. https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

Photo 19: *Close up view of barley heads affected with loose smut.*

Source: DAFWA

If the spores settle on healthy flowers, they may germinate and infect the embryo of the developing seed. When this seed is planted, the smut grows inside the plant until flowering when the disease appears. Because loose smut is carried inside the seed, systemic seed dressings are needed to control it. These are more expensive than the others and should be used only when a high incidence of loose smut is expected. [62]

Managing smut

The disease is controlled by pickling seed with a systemic fungicide which penetrates the developing seedling to kill the internal infection. Cereal seed dressing fungicides differ in their efficacy for smut management with trial research demonstrating that some seed dressings can reduce the incidence of loose smut in heavily infected seed to nearly zero. The correct application of seed dressings is critical to ensuring adequate control. In-furrow and foliar fungicide applications are not effective. [63]

9.8 Common root rot

Common root rot (*Bipolaris*) is a soil-borne fungal disease which attacks cereals. It survives from one season to the next through fungal spores, which remain in the cultivated layer of the soil. The disease increases in severity with continuous cereal sequences.

Common root rot is not common in WA but can build up to damaging levels in continuous wheat crops. [64]

Common root rot symptoms:

- a dark-brown to black discolouration of the stem just below the soil surface
- black streaks on the base of stems
- slight root rotting.

62 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

63 DAFWA. (2016). Smut and Bunt diseases for cereal. https://www.agric.wa.gov.au/autumn/smut-and-bunt-diseases-cereal-biology-identification-and-management?page=0%2C0

64 DAFWA. (2015). Diagnosing common root rot of cereals. https://www.agric.wa.gov.au/mycrop/diagnosing-common-root-rot-cereals

9.8.1 Damage caused by disease

Common root rot can cause yield losses of between 10–15% in susceptible varieties.

9.8.2 Symptoms

Paddock

- Affected plants tend to be scattered over a paddock, and they may be slightly stunted, have fewer tillers and produce smaller heads.

Plant

- Browning of roots and sub-crown internode (the piece of stem emerging from the seed to the crown) (Photo 20).
- Blackening of sub-crown internode in extreme cases.

Photo 20: *Blackening of sub-crown internode in extreme cases.*

Source: SARDI in DAFWA

9.8.3 Conditions favouring development

- Can occur from tillering onwards but most obvious after flowering
- No distinct paddock symptoms, although the crop may lack vigour
- Severe infections can lead to stunting of plants.
- Appears more prevalent in paddocks that are N deficient. When N is not limiting, yield loss occurs through a reduction in tillering due to poor N use efficiency
- Affected plants are usually scattered through the crop
- Widespread through the grain belt; often found in association with Crown Rot.

- The fungus that causes common root rot survives on the roots of grasses and as dormant spores in the soil. It can build up to damaging levels in continuous wheat rotations. [65]

Infection is favoured by high soil moisture for six to eight weeks after planting.

9.8.4 Management

The disease may be controlled by planting partially resistant varieties or by crop rotation. Where the disease is severe, rotation to non-susceptible crops for at least two years is recommended. Summer crops such as sorghum, sunflower, or white French millet can be used for this purpose. [66]

- Reduce levels of the fungus in your paddocks by rotating with crops such as field pea, faba bean, canola, mustard, mungbean, sorghum or sunflower.
- Weak crops or pasture must be grass-free.
- Sow partly resistant wheat or barley varieties.
- If moisture permits, reduce sowing depth to limit the length of the SCI (sub-crown internode).
- Ensure adequate nutrition especially of phosphorus which reduces severity.
- Burning does not decrease spore levels in the soil. [67]

9.9 Ergot

Triticale, like rye, is susceptible to ergot, a fungal disease that can ruin a year's crop. Careful crop rotation, the use of a clean seedbed, and diligent maintenance of field edges will minimize this chance. Triticale intended for human or animal consumption should be tested for toxins. Ergot can make grain less palatable for livestock as well as causing serious health problems. [68]

9.9.1 Damage caused by disease

Ergot bodies contain alkaloid chemicals that can cause lameness, gangrene of the extremities and nervous convulsions (staggers) that can lead to death in both humans and animals. As these toxins accumulate in the body, symptoms can begin to occur after long periods of low level ingestion. Crops affected by Ergot generally do not experience significant yield losses, but economic losses can be quite severe when grain tendered by growers is rejected at receival. [69]

Gangrenous ergotism of man and cattle;

Blockage of circulation to the extremities, tingling in the fingers, vomiting, diarrhoea, gangrene of the toes and fingers, ulceration of the mouth. It is a dry form of gangrene and limbs may fall off. In cattle there is lameness, especially in the hindquarters, gangrene of feet, ears and tail. Pregnant cows may abort. There is a characteristic band where the gangrenous tissue ends.

Convulsive ergotism;

Symptoms similar to those of gangrenous ergotism and are followed by painful spasms of the limbs, epileptic convulsions and delirium in man. Cattle become excitable and run with a swaying uncoordinated gait. [70]

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65 Moore K, Manning B, Simpfendorfer S, Verrell A. NSW DPI. Root and crown diseases of wheat and barley in Northern NSW. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/159031/root-crown-rot-diseases.pdf

66 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

67 Moore K, Manning B, Simpfendorfer S, Verrell A. NSW DPI. Root and crown diseases of wheat and barley in Northern NSW. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/159031/root-crown-rot-diseases.pdf

68 UVM. (2011). Triticale. http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

69 AWB. Wheat Quality Factsheet – ERGOT.

70 Collated by HerbiGuide. Phone 08 98444064 or www.herbiguide.com.au for more information. http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

9.9.2 Symptoms

Characteristically Ergot pieces have a purple – black surface with a white to grey interior (Photo 21). They are usually horn like in shape and replace one or more grains in the heads of cereals and grasses. These Ergot bodies can be up to four times larger than normal grain.

What to look for

In crop

- Hard dry purple-black fungal bodies (ergots) that replace the grain in the seed head.
- Yellow droplets of sugary slime in infected heads during flowering. [71]

Photo 21: *Ergot bodies in cereal grain head.*

Source: Natgeocreative

In stock

In WA the most common symptom of ergot poisoning in livestock is hyperthermia. [72] Producers are encouraged to keep an eye on animals eating ergot-infected grain in hot or sunny weather (Photo 22). Signs of ergot poisoning include animals seeking shade, being reluctant to move, and panting and distress following any exercise. Animals may also drool, have an increased respiratory rate and reduced feed intake. [73]

71 DAFWA. (2015). Diagnosing Ergot. https://www.agric.wa.gov.au/mycrop/diagnosing-ergot

72 DAFWA. (2014). WA Livestock disease outlook. http://www.wafarmers.org.au/wp-content/uploads/2014/04/Producer-edition-WA-Livestock-Disease-Outlook-April-2014.pdf

73 DAFWA. (2015). Look out for ergots when selecting stock feed. https://www.agric.wa.gov.au/news/media-releases/look-out-ergots-when-selecting-stock-feed

Photo 22: *Producers need to be aware that even a small amount of ergot in grain can cause serious illness to their stock.*

Photo: Michael Raine

9.9.3 Conditions favouring development

Key points:

- Ergots survive in the soil for up to one year, producing spores that infect plants during flowering.
- Infection prefers cool wet weather at flowering.
- Spread by rain-splash or by insects attracted to the sugary droplets.
- High levels of grass-weed contamination can increase ergot infection in cereals, or ergots produced in grasses can contaminate grain samples. [74]

The development of Ergot is favoured by moist soil surfaces during spring and early summer. In addition, wet conditions during flowering of cereals and grasses increases the period of infection. The disease cycle of Ergot consists of two stages. The cycle begins in spring when the Ergot bodies germinate in wet soils after a period of cold temperatures (winter) and develop fruiting bodies that contain spores (ascospores). These spores can be spread to neighbouring susceptible plants by wind and rain. To infect these plants, the spores must land on the florets and within five days the second stage commences, referred to as the "honeydew stage". During this stage the infected florets exude a sugary slime that contains spores (conidia). These spores can in turn infect other florets via insect vectors, rain splash and/or wind. This period of infection lasts for as long as the susceptible plants are in flower. The infected ovary in the floret then enlarges and is replaced by the purple – black Ergot body that can survive in soil for up to one year. Crops are generally perceived to be at greatest risk when grass weed populations are high. Infected grasses usually produce slender Ergots and in some cases can be fully responsible for the contamination of grain samples. [75]

Ongoing periods of spring and summer rain can increase occurrence of ergots in ryegrass, therefore Ergots in crop are more likely to develop in years of above-average rain when ryegrass is flowering. [76]

9.9.4 Management of disease

Key points:

74 DAFWA. (2015). Diagnosing Ergot. https://www.agric.wa.gov.au/mycrop/diagnosing-ergot

75 AWB. Wheat Quality Factsheet – ERGOT.

76 DAFWA. (2015). Look out for ergots when selecting stock feed. https://www.agric.wa.gov.au/news/media-releases/look-out-ergots-when-selecting-stock-feed

- Give contaminated paddocks a one-year break without cereals or grasses.
- Manage grass weed contamination in crops.
- Seed cleaning. [77]

For grain that is contaminated with pieces of Ergot, grain-cleaning equipment can be used to remove the majority of Ergot bodies (Photo 23). However, the grower will need to determine whether this is an economically viable option.

Photo 23: *Ergot contaminated seed.*

Source: DPI Vic, in DAFWA

To avoid the development of Ergot in subsequent cereal crops, effective farm management practices are required. One option available to growers is the use of crop rotations away from cereals for at least one year to reduce the amount of viable Ergot pieces in the soil to negligible levels.

During planting clean seed must be used, as there is currently no effective treatments against Ergot. For growers using conventional tillage, Ergot pieces need to be buried to a minimum depth of 4 cm. This prevents the fruiting bodies that are produced by the Ergot from reaching the soil surface and releasing spores. This may have an effect on the usual sowing operations and guidance should be sought.

Finally, to eliminate the development of host reservoirs growers may be able to mow or spray grass pastures to prevent flowering. [78]

77 DAFWA. (2015). Diagnosing Ergot. https://www.agric.wa.gov.au/mycrop/diagnosing-ergot

78 AWB. Wheat Quality Factsheet – ERGOT.

Control of grasses within cereal crops will help prevent cross infection. This is best achieved by preventing seed set in the season before cropping, by clear fallowing, hard grazing or hay cutting, together with the use of selective herbicides. [79]

The only practical control is to sow clean, year-old seed on land that hasn't grown cereal rye for at least a year. Mowing roadside and headland grass prior to seed set will reduce or eliminate this major source of ergot re-infestation. [80]

Strategies to reduce the risk of ergot infection:

- Use ergot-free seed if possible.
- Rotate with crops resistant to ergot, such as flax, canola and legumes.
- As the source of ergot infection is often the grass in headlands or ditches, mowing this grass before flowering or seed set will greatly reduce or eliminate the chances of ergot infection.
- Ergots germinate at or near the soil surface to produce infectious spores that attack cereal flowers. To prevent them from germinating, work the field to a depth greater than two inches to bury the ergot bodies.
- Seed at a uniform depth as shallow as possible for adequate moisture to obtain a uniform early emergence.
- Separate the seed collected from the first few combine rounds to prevent contamination of the entire lot as most of the ergot infested grain will likely be concentrated in this region. [81]

Marketing options

Stockfeed intended for feedlot cattle has been further limited to 0.1% sclerotes by weight since 2004.

Deliveries of sorghum with sclerote levels higher than 0.3% will be rejected by grain merchants, and higher than 0.1% will be rejected by cattle feedlotters. Most commonly, a sorghum sample containing 0.3% sclerote will contain about 1 mg alkaloid/kg (1 ppm), but because the alkaloid concentration can vary, it will be advisable to minimise ergot wherever possible.

Although there is a 0.3% sclerote contamination limit for sorghum intended for livestock, some end-users will not accept ergot-contaminated grain at all. Grower pigs, chickens and laying hens are most tolerant of the alkaloids in sclerotes, and so are a potential market for sorghum that contains 0.3% sclerotes. Sorghum with levels higher than the animal feed limit can be mixed with clean grain to reduce the sclerote levels. Fortunately, the incidence of ergot contamination of bulk grain has been extremely low over the past few years. [82]

9.10 Cereal fungicides

All of the diseases addressed so far are caused by different fungi. Fungal disease is a major disease threat to all Australian crops.

Key points:

- Fungicides are only one component of a good management strategy.
- Correct identification of the cause of plant symptoms is essential, and an understanding of the growth and spread of any pathogen will assist in any decision making.
- Cultivar resistance is the best protection against fungal diseases. Ideally, when agronomically suitable varieties are available, opt for moderately resistant (MR) to resistant (R) varieties in disease-prone environments.

79 Agriculture Victoria. (1999). Ergot of pasture grasses. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/ergot-of-pasture-grasses

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

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

82 DAFF QLD. (2010).Ergot-affected and mouldy sorghum. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/ergot-affected-and-mouldy-sorghum

- Disease control using fungicides is an economic decision.
- Understand the role of the season and have a plan in place, and if growing susceptible varieties have the right chemicals on hand.
- For cereal rusts and mildew, remove the green bridge between crops to prevent rusts from over-seasoning.
- Monitor crops throughout the season.
- Spray if disease threatens key plant parts (flag to flag-2) of varieties that are moderately susceptible (MS) or susceptible (S).
- Fungicides do not increase yield; they protect yield potential and cannot retrieve lost yield if applied after infection is established.
- Fungicide resistance is a major emerging issue. Do not use tebuconazole-based products on barley if there is any chance of powdery mildew occurring, and select varieties that are resistant to powdery mildew (Table 5).

Table 5: *Modes of action registered for control of foliar diseases in Australian cereals.*

Group	Active ingredient	Example product name	Foliar (F), seed (S) or in-furrow (IF)
	Triadimefon	Triad®	F and IF
	Propiconazole	Tilt®	F
	Propiconazole + cyproconazole	Tilt® Xtra	F
	Tebuconazole	Hornet®	F and S
3 - DMI	Flutriafol	Impact®	F and IF
	Tebuconazole + flutriafol	Impact® Topguard	F
	Tebuconazole + prothioconazole	Prosaro®	F
	Epoxiconazole	Opus® 125	F
	Triadimenol	Baytan®	S
	Fluquinconazole	Jockey®	S
3 + 11 (Stobilurins)	Azoxystrobin + cyproconazole	Amistar® Xtra	F
	Pyraclostrobin + epoxiconazole	Opera®	F

Source: Oliver R, Curtin University in GRDC

VIDEOS

WATCH: GCTV9: Banding Fungicide in Cereals.

9.10.1 Fungicide stewardship

There have been a number of pathogens, such as *Septoria tritici* blotch, which have recently developed a level of fungicide insensitivity/resistance in Australia. The occurrence of these highlights the important role all growers play in fungicide resistance management.

To help achieve fungicide resistance management and disease management, there are three important steps growers need to implement.

1. Remove the source of infection.

- For many pathogens, stubble is the source of the infection each year. By removing stubble before sowing, there is a substantial reduction of pathogen population size.
- This reduces all forms of the pathogen irrespective of resistance and reduces the initial establishment of disease.
- Do not sow wheat on wheat or barley on barley to avoid rapid disease build-up.

2. Variety choice.

- Under high disease pressure, a variety rated MR-MS can reduce the leaf area loss substantially. Where possible, choose a more resistant variety.
- Host resistance reduces all forms of the pathogen irrespective of resistance and reduces the need for multiple canopy fungicide applications.
- But resistance ratings do change so crops must still be monitored in season for higher than expected reactions and check each year for updates to disease ratings.

3. Fungicide choice and use.

- Do not use the same triazole active ingredient more than once in a season. Do not use a strobilurin or Succinate DeHydrogenase Inhibitors (SDHI) more than once in a season.
- Aim for early control of necrotrophic diseases in high rainfall years. Reducing the disease in the lower canopy slows the upward movement of disease and ultimately the leaf area lost.
- Follow label instructions at all times.

Timing of application in the disease epidemic is critical to getting the most out of these products. [83]

Which foliar fungicide active ingredients are registered for which cereal diseases in WA? The DAFWA provide details on how to apply fungicides effectively and minimise the risk of fungicide resistance developing. For details on foliar fungicide application rates, adjuvants, withholding periods and other instructions please refer to product labels.

MORE INFORMATION

Registered foliar fungicides for cereals in Western Australia

Seed dressing and in-furrow fungicides for cereals in Western Australia

GRDC Cereal Fungicides Factsheet.

9.11 Barley yellow dwarf virus (BYDV)

The yellow dwarf diseases of cereals have now been divided into two groups, barley yellow dwarf virus (BYDV) and cereal yellow dwarf virus (CYDV). They are the most important virus diseases of cereals worldwide. They have a wide host range which includes triticale, wheat, barley, oats and over 150 grass species. These viruses are not seed-borne and persist from one growing season to the next in oversummering grasses. BYDV and CYDV infection decreases grain yield and also causes shrivelled grain. These viruses can cause serious problems in cereal crops in the southern and south-west agricultural areas of WA (more than 500 mm of rain). BYDV is often more prevalent than CYDV. [84]

The virus is usually spread by aphids from infected grasses to crops. Wet summers and autumns promote growth of host grasses and build-up of aphid vectors resulting in early crop infection, severe symptoms and yield losses. Yellow dwarf viruses (YDV) can occur in all cropping regions. The virus is best controlled by monitoring and spraying for aphids early in the season.

Economic importance

The effect of the disease on yield depends on the viral species or strain, time of infection and rate of spread. Ten per cent yield losses may occur without visible symptoms of infection, with severe losses approaching 80% when infection is early. Trials with wheat in WA have shown that yield losses caused by BYDV infection vary greatly between varieties depending on their tolerance or susceptibility to the virus. Yields of sensitive varieties were reduced by up to 67 %. Similar losses develop in barley and oats. [85] Trial data has shown that yield losses of between 9–79% can occur when plants are infected early in the growing season (before the end of tillering) and losses of 6–9% may occur when plants are infected late (post tillering). [86]

83 Milgate A. (2016). Cereal disease update and risks for southern NSW crops in 2016. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Cereal-disease-update-and-risks-for-southern-NSW-crops-in-2016

84 Coutts B. (2015). Managing barley yellow dwarf and cereal yellow dwarf virus in cereals. DAFWA. https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals

85 Coutts B. (2015). Managing barley yellow dwarf and cereal yellow dwarf virus in cereals. DAFWA. https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals

86 Agriculture Victoria. (2011). Barley Yellow Dwarf Virus. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/barley-yellow-dwarf-virus

9.11.1 Symptoms

Symptoms take at least three weeks to appear after infection. They usually appear as patches of yellow or red stunted plants. The symptoms first appear where aphids have landed. Flying aphids may infect individuals or groups of plants dotted throughout the crop. If the aphids colonise the crop rings or patches develop which increase in size with time (Photo 24). If crawling aphids move into the crop from adjoining pastures or crops then symptoms will appear along the fence line first.

Photo 24: *Patches where aphids have landed and transmitted the virus emerge in paddocks.*

Source: DAFWA

YDV symptoms can be variable and can differ with host species, cultivar and time of infection. Sometimes, infection of cereals may occur without visible symptoms. Distinct symptoms usually occur on cereals although many infected grasses are symptomless. [87]

Infected wheat plants develop a slight to severe yellowing or pale striping between veins (interveinal chlorosis) in young leaves (Photo 25). Leaf tips can also die (necrosis). Reddening of the leaf tips (particularly of the flag leaf) can often be seen and is the most characteristic symptom of virus infection in wheat. If a sensitive variety is infected before tillering, the plant is usually stunted, has fewer tillers and more sterile ones. Grain matures early, yield is greatly reduced and grain is shrivelled. Effects are milder with a late infection. [88]

87 Agriculture Victoria. (2011). Barley Yellow Dwarf Virus. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/barley-yellow-dwarf-virus

88 Coutts B. (2015). Managing barley yellow dwarf and cereal yellow dwarf virus in cereals. DAFWA. https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals

Photo 25: *Barley yellow dwarf virus infection of a cereal plant.*

Source: DAFWA

9.11.2 Conditions favouring development

The YDVs have a very wide host range in the grass family (Poaceae). They survive between cropping seasons in volunteer cereals, annual and perennial pasture grasses and wild grasses. The virus and vectors can survive in small pockets of surviving grass even in the low rainfall areas. The aphid vectors of the viruses tend to build up in autumn and spring on the grasses, and then move into cereal crops where they often develop colonies. High rainfall areas have a greater build up of the grasses, virus and vectors.

There are at least six serotypes of the YDVs which are spread predominantly by different aphid vectors. The distribution and relative importance of the different types are largely dictated by the abundance of the aphid vector species. If samples are being tested, tests should include serotype PAV, MAV, RMV for (BYDV) and RPV for (CYDV).

In Western Australia (WA), the virus is spread mainly by the oat (*Rhopalosiphum padi*) and the corn leaf (*Rhopalosiphum maidis)* aphids. The oat aphid is the most important; it feeds on wheat, barley, oats and grasses. The corn leaf aphid usually only feeds on barley and some grasses. Other minor aphid vectors include the grain aphid (*Sitobion sp*.) and two cereal root aphids (*Rhopalosiphum insertum* and *Rhopalosiphum rufiabdominalis*). [89] The viruses are not transmitted by any other insects and are not transmittable through seed, soil or sap. The aphids need to feed on an infected plant for at least 15 minutes followed by a latent period of 12 hours, before the virus will transmit to a healthy plant. Aphids remain infected for the rest of their life.

See Section 7: Insect control for more information on aphids.

YDV outbreaks are likely to be worse in years when wet cool summers allow larger than normal numbers of aphids and alternate hosts to survive summer; followed by a mild winter which favours the build up of aphid numbers. Early sown crops or long season crops sown in high rainfall areas are particularly vulnerable to this disease. [90]

89 Coutts B. (2015). Managing barley yellow dwarf and cereal yellow dwarf virus in cereals. DAFWA. https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals

90 Agriculture Victoria. (2011). Barley Yellow Dwarf Virus. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/barley-yellow-dwarf-virus

9.11.3 Management

Where resistant varieties are not an option the management of aphid activity in crops especially early in the season to prevent its spread and or delayed sowing to avoid the main aphid flights in the autumn can reduce YDV infection.

Later sowing to avoid the main aphid flights will reduce the incidence of YDV but this needs to be weighed up against possible yield reduction from delayed sowing.

Resistant varieties when available are the preferred option for management. There are a number of oat and a couple of wheat and barley varieties with varying levels of resistance.

Chemical treatments

It is vital to prevent spread of the virus by aphids during the first 8–10 weeks after crop emergence using insecticides. In situations where aphids are likely to be a problem in the first few weeks after sowing, a seed treatment containing imidacloprid could be used for protection.

Foliar sprays can be used early after crop emergence if aphids are easily found. There are a number of products registered for control of aphids in cereals. The active ingredient pirimicarb only effects aphids and will have less effect on any beneficial insects present at the time of spraying. Synthetic pyrethroids are also registered for use on aphids in cereals but will have a detrimental effect on many beneficial insects. You will need to discuss with your agronomist the insecticide best suited to your situation. [91]

MORE INFORMATION

Managing barley yellow dwarf virus and cereal yellow dwarf virus in cereals

Diagnosing yellow dwarf virus

Insecticides

Strategic applications of insecticides can be used against the aphids that carry BYDV or CYDV to reduce its spread. It is important to protect the crop during the first 10 weeks after emergence. First pyrethroid spray: 3 weeks after emergence (or 2-leaf stage if aphids easily found). Second pyrethroid spray: 7 weeks after emergence. In high risk situations, seed dressings containing imidacloprid applied to seed before sowing are recommended for good early season control but requires a follow-up pyrethroid spray. [92]

Delayed Sowing

Later sowing to avoid the main aphid flights will reduce the incidence of YDV but this needs to be weighed up against possible yield reduction from delayed sowing. [93]

9.12 Disease following extreme weather events

9.12.1 Cereal disease after drought

Drought reduces the breakdown of plant residues. This means that inoculum of some diseases does not decrease as quickly as expected, and will carry over for more than one growing season, such as with crown rot. The expected benefits of crop rotation may not occur or may be limited. Inversely, bacterial numbers decline in dry soil. Some bacteria are important antagonists of soil-borne fungal diseases such as common root rot. These diseases can be more severe after drought.

Within the drought year, inoculum of some diseases favoured by a wet season may not increase as expected.

91 Agriculture Victoria. (2011). Barley Yellow Dwarf Virus. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/barley-yellow-dwarf-virus

92 Coutts B. (2015). Managing barley yellow dwarf and cereal yellow dwarf virus in cereals. DAFWA. https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals

93 Agriculture Victoria. (2011). Barley Yellow Dwarf Virus. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/barley-yellow-dwarf-virus

Large amounts of seed produced in abandoned crops, or pinched seed from drought stress, will fall to the ground. If there are summer rains, large numbers of volunteers will provide a summer green bridge and autumn green ramp.

Low stock numbers make it difficult to control these volunteers, which provide a green bridge for rusts, viruses and virus vectors, and many other pathogens.

Weeds that harbour diseases are harder to kill.

Soil water and nitrogen may be unbalanced and these are likely to impact on diseases. [94]

9.12.2 Cereal disease after flood

For disease to occur, the pathogen must have virulence to the particular variety, inoculum must be available and easily transported, and there must be favourable conditions for infection and disease development.

The legacy of the floods and rain included transport of inoculum (crown rot, nematodes, leaf spots through movement of infected stubble and soil) (Photo 26), development of sexual stages (leaf spots, head blights), survival of volunteers (unharvested material and self-sown plants in double-crop situations), and weather damaged seed. [95]

Photo 26: *Tan spot infected stubble following flood.*

Photo: Rachel Bowman, Seedbed Media

94 Murray G, Hind-Lanoiselet T, Moore K, Simpfendorfer S, Edwards J. (2006). Crop diseases after drought. Primefacts 408 NSW DPI.

95 DAFF (2013) Winter cereals pathology. Department of Agriculture, Fisheries and Forestry Queensland, https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/prepare-for-winter-crops-following-floods/winter-cereals-pathology

Plant growth regulators and canopy management

Key messages

- In Australian cereal production plant growth regulators (PGRs) are mostly used with the intention of producing a smaller plant that is resistant to lodging or they are applied with the intention of reducing excessive growth in irrigated broadacre crops.
- Trials have revealed mixed responses in crop yield to the application of PGRs.
- Canopy management includes a range of crop management tools to manage crop growth and development to maintain canopy size and duration to optimise photosynthetic capacity and grain production
- Canopy management starts at seeding: sowing date, variety, plant population and row spacing are fundamental. It is more than purely delaying nitrogen.
- So far the best results for canopy management have been seen in early sown – long season varieties with high yield potential which are very N responsive with high N fertiliser inputs. [1]

10.1 Plant growth regulators (PGRs)

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. [2]

The growth of triticale seedlings from seeds treated with three concentrations of the plant growth regulators (PGRs), tetcyclacis and chlormequat, with or without drying after soaking has been investigated. Both tetcyclacis and chlormequat inhibited shoot growth. They reduced shoot:root ratios, first by restricting shoot growth (one week after treatment) and later by boosting root growth (eight weeks after transplanting). At the concentrations used tetcyclacis was a more active PGR than chlormequat and promoted tiller production. Drying, after soaking, promoted root growth, retarded the elongation growth of seedlings and enhanced some of the effects of the PGRs. [3]

In another study, seeds of triticale and barley were soaked in a range of dilutions of chlormequat. Germination was monitored and the growth of seedlings assessed for up to five weeks. Some concentrations of chlormequat produced seedlings with significantly more leaves on the main stem, more primary tillers, a greater leaf lamina area and a higher shoot dry weight. It is argued that these modifications could lead to an increased yield potential. [4]

In Australia there have been mixed results in terms of PGR ability to increase yield and profits.

Take home messages:

- Crop responses to the use of plant growth regulators (PGRs) can be inconsistent.
- In general, yield responses, if any, are produced by the reduction in lodging rather than as a direct effect of the PGRs (Photo 1).

1 McMullen G. (2009). Canopy management in the Northern grains region – the research view. NSW DPI. http://www.nga.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf

2 Lemaux P. (1999). Plant growth regulators and biotechnology. http://ucbiotech.org/resources/biotech/talks/misc/regulat.html

3 Yang, W., & Naylor, R. E. L. (1988). Effect of tetcyclacis and chlormequat applied to seed on seedling growth of triticale cv. Lasko. *Plant growth regulation*, *7*(4), 289–301.

4 Naylor, R. E., Brereton, P. S., & Munro, L. (1989). Modification of seedling growth of triticale and barley by seed-applied chlormequat. *Plant growth regulation*, *8*(2), 117–125.

- In ICC trials however, yield increases that may be attributed directly to the use of PGRs have been measured in barley but not wheat.
- Plant growth regulators must be applied at the correct crop growth stage according to product directions, which can be well before any lodging issues are apparent.

Photo 1: *Severe lodging of a cereal crop (left).*

Source: Syngenta

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. However, in most of the newer varieties lodging is not considered a problem. The likelihood of lodging is increased by high rates of nitrogen fertiliser and under irrigated conditions. [5] PGRs may help to decrease the risk of lodging in triticale, however, this has not been explored in Australia.

Attempting to grow high yielding irrigated crops requires high levels of inputs; including water and fertiliser, which can promote large vegetative crops that increase the risk of lodging. Lodging can result in reduced yields and difficult harvest. Plant growth regulators have been around for many years but results can be variable, even having negative effects on yield. The Irrigated Cropping Council (ICC) conducted trials in 2003 and 2004 that saw some reduction in lodging but little yield response. At the same time, trials on nitrogen management in cereals demonstrated that to achieve high yields, crops do not necessarily need heavy sowing rates and large amounts of nitrogen at sowing, with corresponding lush crop in early season prone to lodging. This has seen many growers adopt a topdressing strategy that supplies the crop with N when it needs it; i.e. from stem elongation onwards. Less vegetation at stem elongation promotes stronger stems, which can support a crop yielding eight t/ha.

A trial conducted at the ICC trial block in 2012 which aimed to grow 10 t/ha of wheat and barley was deliberately sown heavy and fertilised early and sprayed with the plant growth regulator, Moddus Evo as lodging was likely to occur. The effect of the PGR was mixed; barley yields increased but wheat yields did not, despite the crops not actually lodging. A repeat trial sown in 2013 saw some lodging control and once again, a yield increase in barley.

Plant growth regulator (PGR) is a term that describes many agricultural and horticultural chemicals that influence plant growth and development. This influence can be positive; e.g. larger fruit or more pasture growth, or negative; e.g. shorter stems or smaller plant canopies. This paper/presentation will focus on the PGRs that have a negative influence on plant growth; i.e. they are applied with the intention of producing a smaller plant that is resistant to lodging or they are applied with the intention of reducing excessive growth in irrigated broadacre crops. Currently, there are four broad groups of PGRs in use in Australian crops. The four broad groups of PGRs are as follows:

1. Ethephon; e.g. Ethrel®.
   - ii. Onium types; e.g. Cycocel®, Pix® *(n.b. Pix® is registered only for cotton).*
   - iii. Triazoles; e.g. propiconazole *(n.b. propiconazole is registered as a fungicide not a PGR)*

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5 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

1. Trinexapac-ethyl; e.g. Moddus®, Moddus Evo (n.b. Moddus® is registered for ryegrass seed crops, poppies and sugar cane. Moddus Evo is an enhanced dispersion concentrate of Moddus, it is not currently registered but has been submitted to the APVMA for registration in Australian cereals)

These PGRs act by reducing plant cell expansion, resulting in, among other things, shorter and possibly thicker stems. If the stems are stronger and shorter than the crop is less likely to lodge.

The majority of the PGRs (groups ii to iv) reduce crop height by reducing the effect of the plant hormone; gibberellin. These are applied at early stem elongation (Z30-32).

Ethephon is applied from flag leaf emerging (Z37) to booting (Z45) and reduces stem elongation through the increase in concentration of ethylene gas in the expanding cells.

Other benefits claimed by the producers of the various products include:

1. Better root development that allows for increased root anchorage.
2. Better root development providing greater opportunity for water and nutrient scavenging.
3. May offer improved grain quality.
4. Reduction in shedding in barley.
5. Increased Harvest Index (the ratio between grain and total dry matter).
6. Faster harvest speeds and reduced stress at harvest.

An alternative to the chemical PGRs is grazing. Demonstrated in the Grain and Graze project on a number of sites was the effect grazing had on the crops where the grazed treatments were regularly shorter than the non-grazed treatments and were less prone to lodging.

Conclusions

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.

The yield improvements seen in barley in the ICC trials need further investigation as the reason behind the increase is not clear. [6]

In Australia, the range of PGR's available to growers is 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.

A 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. [7] Overseas, chlormequat chloride has been found to inhibit gibberellin production and has been recommended in triticale, rye, wheat, oats, and winter barley. [8]

Moddus Evo

Key points:

- Moddus Evo reduces lodging and can increase yields

MORE INFORMATION

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 – TAS.

6 Jones D. (2014). GRDC Update Papers: Plant Growth Regulators. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators

7 Long W. (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

8 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

- 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.

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 to 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 either 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.

10.2 Canopy management

Key points:

- canopy management starts at seeding: sowing date, variety, plant population and row spacing are fundamental. It is more than purely delaying nitrogen.
- correct identification of the key growth stages for input application is essential, particularly during early stem elongation when the key leaves of the crop canopy emerge.

- Knowledge of soil moisture status and soil nitrogen reserve and supply need to be taken into account in order to match canopy size to environment.
- crop models can help integrate crop development, environmental conditions and nutrient status in order to make better canopy management decisions. [9]

What is canopy management?

The concept of canopy management has been primarily developed in Europe and New Zealand – both distinct production environments to those typically found in most grain producing regions of Australia.

Canopy management includes a range of crop management tools to manage crop growth and development to maintain canopy size and duration to optimise photosynthetic capacity and grain production (Photo 2). 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 inputs are tactically delayed until later in the growing season. This delay tends to reduce early crop canopy size but this canopy is maintained for longer, as measured by green leaf retention, during the grain filling period. [10]

Photo 2: *Examples of controlled canopy cover. Thinner crop canopy (left) yield = 6.18 t/ha and 12% protein and thicker crop canopy (right) yield = 6.20 t/ha and 10.6% protein. Kellalac wheat sown 11th June Gnarwarre (Geelong region), Victoria (in high rainfall zone) region treated with same level of nitrogen.*

Source: GRDC

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[11] and one of the main tools for growers to manage the crop canopy is the rate and timing of applied fertiliser N.

If the canopy becomes too big, it competes with the growing heads for resources, especially during the critical 30-day period before flowering. This is when the main yield component (grain number per unit area) is set. Increased competition from the canopy with the head may reduce yield by reducing the number of grains that survive for grainfill.

9 GRDC. (2009). Canopy management factsheet. https://grdc.com.au/__data/assets/pdf_file/0014/202523/canopy-management.pdf.pdf

10 McMullen G. (2009). Canopy management in the Northern grains region – the research view. NSW DPI. http://www.nga.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf

11 https://www.researchgate.net/file.PostFileLoader.html?id=5780fa6bf7b67e860b4def31&assetKey=AS%3A381929540079624%401468070506798

After flowering, temperature and evaporative demand increase rapidly. If there is not enough soil moisture, the canopy dies faster than the grain develops and results in small grain. Excessive N application and high seeding rates are the main causes of excessive vegetative production. Unfortunately, optimum N and seeding rates are season dependent. Under drought conditions, N application and seeding rates that would be regarded as inadequate under normal conditions may maximise yield, whereas higher input rates may result in progressively lower yields. Alternatively, in years of above average rainfall, yield may be compromised with normal input rates. The extreme of this scenario of excessive early growth is haying-off, where a large amount of biomass is produced, using a lot of water and resources. Then, later in the season, there is insufficient moisture to keep the canopy photosynthesising and not enough stored water-soluble carbohydrates to fill the grain. Therefore, grain size and yield decrease.

To attain maximum yield, it is important to achieve a balance between biomass and resources. The main factors that can be managed are:

- plant population
- row spacing
- inputs of N
- sowing date
- weed, pest and disease control
- plant growth regulation with grazing or specific plant growth regulator products

Of these, the most important to canopy management are N, row spacing and plant population. [12]

Applying nitrogen (N) or fungicide at stem elongation increases the opportunity to match input costs to the potential yield for that season. While seeding applications may still be required for healthy establishment, crop models help support decisions on application timing. Models such as APSIM and Yield Prophet® simulate growth stage and season.

However, canopy management is not about a delayed N strategy but starts at seeding by determining the correct plant establishment for the chosen seeding date and row spacing. This must also take into account available soil moisture and nutrients (Figure 1). [13]

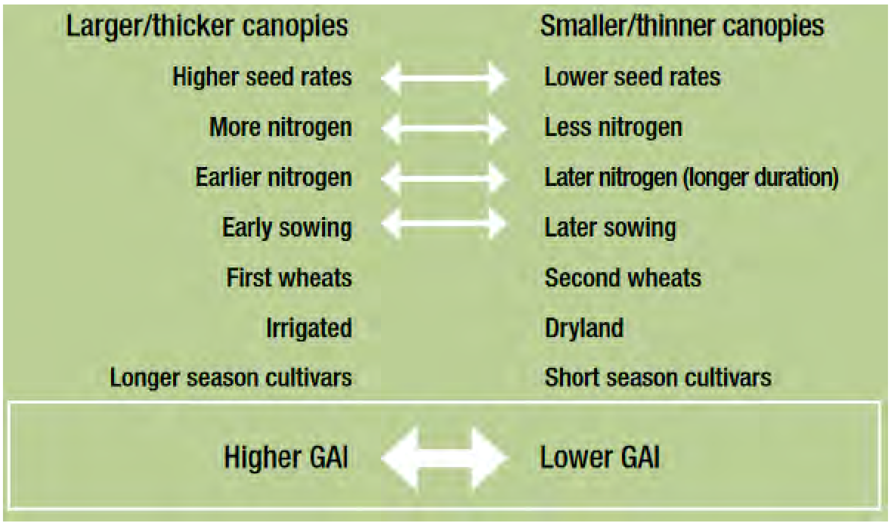

Figure 1: *Factors under grower control that influence canopy density, size and duration. NOTE: GAI = Green area index (amount of green surface area).*

Source: GRDC

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

13 GRDC. (2009). Canopy management Factsheet. https://grdc.com.au/__data/assets/pdf_file/0014/202523/canopy-management.pdf.pdf

While N timing and rate are key components of successful canopy management, it is essential that they are considered in conjunction with the inter-related factors of:

- soil moisture;
- soil nitrogen reserves;
- seeding date; and
- seed rate and variety.

To practice canopy management it is important to understand the principal interactions between plant growth stages, available water and nutrients, and disease pressure. These interactions are complex but tools from simple visual indicators through to crop models can assist.

10.2.1 Canopy management in WA

A well-managed canopy has an optimal number of tillers (providing green leaf area) for any given season so that moisture is conserved for efficient grain-fill.

Canopy management trials near Wagin, Western Australia, indicate medium plant density (120 plants per square metre) and tactical nitrogen applications during the growing season can pay off with higher yields – especially in years with a drier-than-average finish.

Yields can be compromised if plant density is too high (180 plants/m^2) and if too much nitrogen is applied at seeding.

Trial sites were set up from 2011 to 2013 at east Wagin, Kulin, Kellerberrin and Kojonup to investigate canopy management parameters for WA cropping regions. At each site, researchers monitored how wheat canopy density affected grain yield and quality and the level of disease and frost damage.

Yield results from 2011 and 2012 were similar for all plant densities and time of nitrogen application across all treatments at the Kulin, Kellerberrin and Kojonup sites, despite very different rainfall patterns in those years, ranging from decile 6–7 to decile 1–2. The yield results were a reflection of the seasonal conditions and the wheat plant's ability to adjust when it is stressed.

However, at the Wagin trial, researchers were able to measure yield responses to seeding rates of 35, 55 and 80 kilograms per hectare and a standard 40 kg/ha of nitrogen applied either all up-front, split at seeding and GS31, or split at seeding, GS14 and GS31.

Findings from the Wagin site in 2012 included:

- the lowest yield of 1.82 t/ha occurred when all nitrogen was applied up-front, combined with a high plant density (180 plants/m^2). These two factors reduced yields significantly (by up to 0.5 t/ha) because the canopy outgrew its yield potential and there was insufficient stored moisture available for grain fill;
- medium seeding rates (plant density of 120 plants/m^2) and split nitrogen produced reliable yields of about 2.33 t/ha;
- the highest yields (2.38 t/ha and 2.23 t/ha) were achieved at low (plant density of 75 plants/m^2) or medium seeding rates and all nitrogen applied up-front;
- crops could reach yield potential using high seeding rate and delayed nitrogen application; and
- ryegrass biomass fell as seeding rate increased.

Yield losses of up to 1 t/ha can occur if in-crop rainfall does not support crops sown at high seeding rates and supplied with the full rate of nitrogen at seeding.

In the Wagin environment, in a low-to-average-rainfall year, growers can target medium sowing rates and be more flexible in applying nitrogen to play the season as it unfolds – without affecting yield.

Restricting canopy growth can conserve soil moisture, reduce disease pressure and allow crops to finish better. Split nitrogen application is a good risk mitigation strategy, especially if the long-term forecast is not promising or if subsoil moisture levels are low. [14]

10.2.2 Cereal canopy management in a nutshell

1. Select a target head density for your environment (350 to 400 heads per square metre 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.
4. Lower end of range (80–100 plants/m^2) – 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.
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:
   - maximise potential grain size and grain number per head;
   - maximise transpiration efficiency;
   - ensure complete radiation interception from when the flag leaf has emerged (GS39); and
   - keep the canopy green for as long as possible following anthesis.

Keeping tiller number just high enough to achieve potential yield will help preserve water for filling grain and increase the proportion of WSCs. 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 (GS30) and can be employed where tiller numbers and soil nitrogen 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. Much of the research on topdressing nitrogen (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. [15]

10.2.3 Setting up the canopy

Research has shown that extra tillers produced by more plants per unit area are more strongly correlated to yield, than extra shoots stimulated by increased nitrogen at seeding.

Boosting tiller numbers with seeding nitrogen results in greater tiller loss between stem elongation and grain fill. This specifically occurs in two situations: low rainfall, short environments and when soil moisture is limited. In these situations moisture and nutrient resources are used prior to stem elongation to produce biomass, which fails to contribute to grain yield. Indeed by diverting these resources to unsuccessful tillers limits the potential of surviving tillers.

Therefore, identifying the correct population for a particular sowing date, soil nitrogen reserve and region, is the basis for setting up the crop canopy.

14 GRDC. (2015). Hot topics: Canopy management in western region. https://grdc.com.au/Media-Centre/Hot-Topics/Canopy-management-in-western-region/Details

15 GRDC (2014), Advancing the management of crop canopies. https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/gc105-canopymanagement

10.2.4 Soil moisture status

Under Australian conditions soil moisture has been identified as the biggest driver of the cereal crop canopy, both in terms of size and duration. Therefore, an understanding of how much water a soil can hold, and how much water a soil is holding at seeding and stem elongation is central to canopy management.

The start of stem elongation (GS30) is the pivotal point for managing the canopy with inputs, as from this point canopy expansion is rapid and soil nitrogen and water reserves can be quickly used.

If soil moisture is limited at the start of stem elongation the ability to manipulate the crop canopy with nitrogen is limited, in many cases the best canopy management is not to apply inputs such as nitrogen and fungicides.

By setting up a smaller crop canopy, modelling demonstrates that limited stored soil moisture can be reserved for use at grain fill, rather than being depleted by excessive early growth. However, in higher rainfall regions and in a good season setting-up a small canopy may result in actual yield falling below potential.

Calculating potential yield and then plotting actual rainfall against decile readings for the region provides a broad picture of whether there will be sufficient soil moisture to consider additional nitrogen inputs at stem elongation.

The decision support tool Yield Prophet®and the Sirius Wheat Calculator (developed in New Zealand) offer simple tools to record and assess multiple options about the relationship between growing plants and the environment including available water and nutrients.

10.2.5 Soil nitrogen

It is important to have an understanding of soil N reserves to the depth of the rooting zone. Generally, 40 to 50 kilograms of N per hectare of soil available N is required to feed a crop to stem

elongation (GS30). Higher soil nitrogen reserves provide much more flexibility in managing the canopy with tactical nitrogen applied during stem elongation.

Timing of deep-soil tests is important. Deep-soil nitrogen tests carried out in summer, several months before seeding may reveal less soil nitrogen than tests carried out after the autumn rain, when greater mineralisation will have occurred.

Providing soil moisture has not been limited or the crop has not been subject to waterlogging over winter, crop appearance at GS30–31 gives a reasonable indication of nitrogen reserves and the justification for nitrogen application at this stage.

However, it is difficult to use visual appearance unless you have a benchmark; this has led to the concept of the N rich strip (Photo 5). [16]

Photo 3: *A large difference in visual appearance: N-Rich strip (110 kg N/ha at seeding) viewed at GS31 on low soil N reserve (25 kg N/ha 0–90 cm). 443 tiller/m2 – N-rich (left) and 266 tillers/m2 (right).*

Source: GRDC

16 GRDC. (2009). Canopy management Factsheet. https://grdc.com.au/__data/assets/pdf_file/0014/202523/canopy-management.pdf.pdf

A useful guide that requires no sophisticated equipment is to apply an excess of nitrogen at sowing, for example 50 to 100 kg N/ha, to a small area of the paddock, approximately 2m by 10m.

During winter and spring by comparing crop vigour (tiller number) and greenness in these small N-rich areas with the rest of the crop, an indication of N supply can be obtained. The advantage of using the plant rather than depending totally on a soil test is that the plant is directly registering soil N supply, rather than soil nitrogen reserve which crop roots may not always be able to access.

This visual difference can be quantified by using crop sensors that measure the light reflectance from the crop canopy. By measuring the reflectance at the red and near infrared wavelengths, it is possible to quantify canopy greenness using a number of vegetative indices, the most common of which is termed the Normalised Difference Vegetative Index (NDVI). This index gives an indication of both biomass present and the greenness of that biomass. This canopy sensing can be done remotely from aircraft/satellites or with a hand-held or vehicle mounted sensor.

10.2.6 Seeding rate and date

Achieving the correct plant population is fundamental if sufficient tillers are to be set. Seeding rates need to be adjusted for seed size and planting date; if this does not occur the first step in controlling the canopy is lost.

How many plants are targeted depends on:

- region – as a general guide drier regions sustain lower plant populations than wetter environments; and
- sowing date – earlier sowings require lower plant populations compared to later sowings, as the tillering window is longer and more tillers are produced per plant.

Overall, earlier planting provides greater opportunities to manipulate the crop canopy during the stem elongation period: the plant's development periods are extended along with the earlier tillering period.

Row spacing

Key points:

- Increased interest in no-till farming has created a trend for wider crop row spacing (Figure 2).
- In general, increasing row spacing up to 50 cm has minimal effect on cereal yield when yield potential is less than 2 tonnes per hectare.
- In higher rainfall areas, where cereal crops have higher potential yields, significant yield decreases have been recorded with wider row spacing (greater than 25 cm).
- The yields of broadleaf crops vary in their response to wider row spacing.
- Precision agriculture allows for easier inter-row sowing and fertiliser applications at wider row spacing. [17]

17 GRDC. (2011). Crop placement and row spacing factsheet – Southern region. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/02/crop-placement-and-row-spacing-southern-fact-sheet

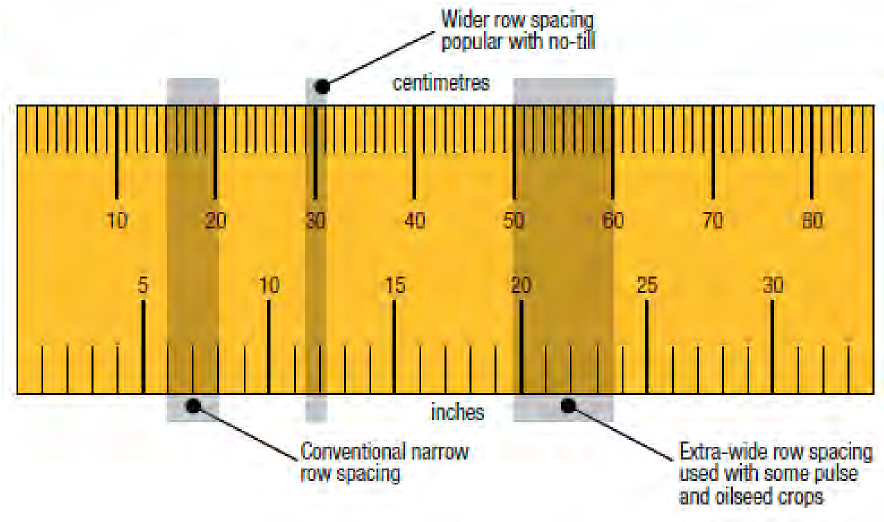

Figure 2: *Common row spacings in metric and imperial measurements.*

Source: GRDC

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 all project trials (2007–10) on wheat covering a wide range of rainfall scenarios, increasing row width reduced yield.
- The yield reduction in wheat was particularly significant when row width exceeded 30 cm.
- Crop row spacing is an important factor for weed competition (Photo 4).
- 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 tonnes per hectare the yield reduction was negligible.
- At yields of 5 t/ha the yield reduction was between 5–7%, averaging about 6%.
- Data from a single site suggests that rotation position may influence the yield response in wider row spacing in wheat. In wheat, wheat-on-wheat suffered less yield reduction with wider rows than an equivalent trial at the same site which was in wheat after canola. [18]

Photo 4: *Narrow row spacing (left) and wide row spacing (right). The higher the yield potential, the greater the negative impact of wider rows on crop yields.*

Source: Weedsmart

18 GRDC. (2014). Advancing the management of crop canopies. https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/gc105-canopymanagement

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).
- Increasing plant populations when using wider rows can be counterproductive with regard to yield, particularly where plant populations exceed 100 plants per square metre as a starting point.
- Limited data indicates that increasing seeding rates such that the average plant to plant spacing in the row drops below 2.5 cm are 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. [19]

Dry Matter

- Wider row (30 cm and over) spacing reduced harvest dry matter relative to narrower rows (22.5 cm and under), with differences growing steadily (kilograms per hectare) from crop emergence to harvest, by which time 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 1 t/ha reduction 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. [20]

Grain quality

- The most noticeable effect of row width on grain quality was on protein, wider rows reduced yield and increased 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. [21]

Nitrogen management

Nitrogen management has not been found to interact with row spacing, optimum N regimes for narrow row spacing (22.5 cm or less) can be the same as for wider row spacing (30 cm or more). The greater nitrogen efficiency observed with stem elongation applied nitrogen was more important with narrow row spacing since higher yields lead to a tendency for lower protein. [22]

10.2.7 In-crop nitrogen

Delaying N inputs from seeding to stem elongation (GS30-31) means they can be better matched to the season. So, in a dry spring no application may be warranted. In spring, with adequate rainfall to justify N application, project trials have shown stem elongation N to give yields equal or better than wheat crops grown with seeding N. However, applying N in advance of a rain front to ensure good incorporation has been found to be more important than exact growth stage. While GS31 should be the target growth stage for in-crop N application, the window can be expanded from GS25 to 31 in order to take advantage of rainfall. Even applications delayed until flag leaf, can be successful where starting soil nitrogen is not too low (Figure 3).

Figure 3 presents the results from winter wheat cropping trials across Australia on the use of in-crop solid nitrogen at stem elongation. This shows that where soil nitrogen

19 GRDC. (2014). Advancing the management of crop canopies. https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/gc105-canopymanagement

20 GRDC. (2014). Advancing the management of crop canopies. https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/gc105-canopymanagement

21 GRDC. (2014). Advancing the management of crop canopies. https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/gc105-canopymanagement

22 GRDC. (2014). Advancing the management of crop canopies. https://grdc.com.au/resources-and-publications/all-publications/publications/2014/01/gc105-canopymanagement

reserves are low, N applied at stem elongation is not always the most appropriate strategy if yield is to be optimised.

Stem elongation N applications were found to be less appropriate with shorter season varieties and late sown crops. Drought conditions during the trial period (2006 to 2008) has limited the results produced from trials. These trials assessed stem elongation N use in cereals grown on wider-row spacings 300 to 350 mm compared to 175 to 200 mm. However, at the same seeding rate, moving to wider rows was found to reduce tillers per unit area and final ear population and yield, the latter by approximately six per cent in the HRZ. [23]

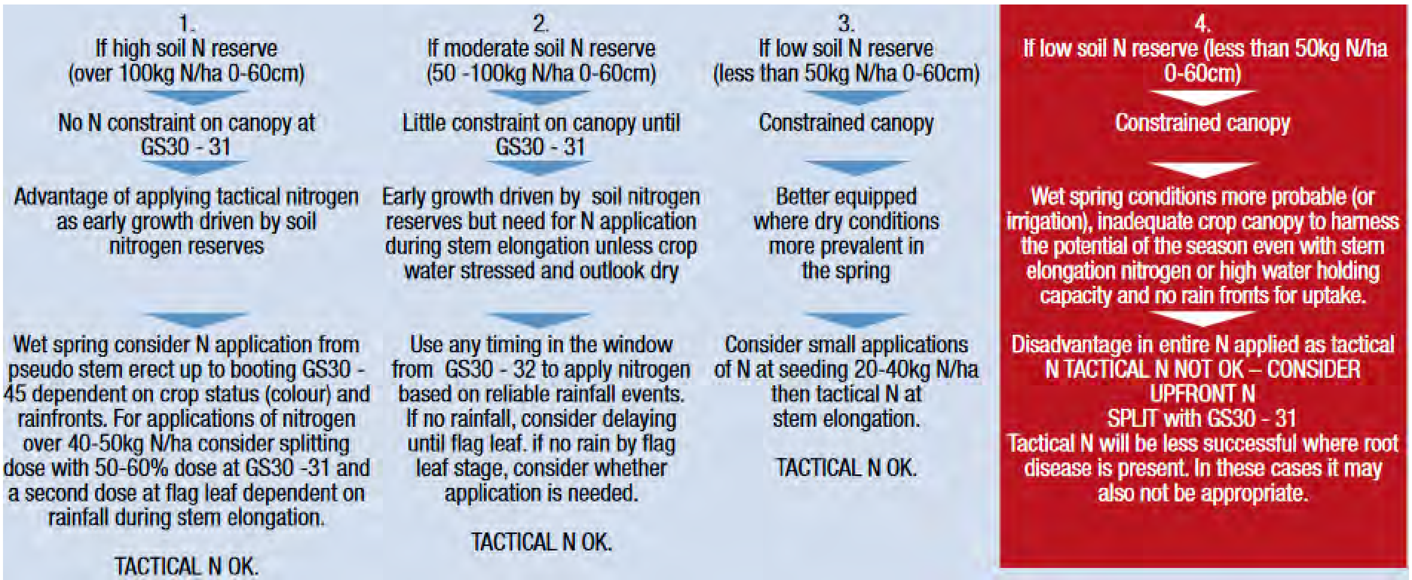

Figure 3: *Broad scenarios based on soil nitrogen level.*

Source: GRDC

10.2.8 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 is risky.

Foliar N application is gaining popularity; however, this is only suitable for relatively low rates of N addition. Where higher N input is required, an efficient system to apply N into the wet soil profile, after a rainfall event, needs to be devised.

As technologies such as NDVI 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 taking shape. Adoption of these techniques would be further aided by development of efficient, in-soil N-application equipment.

MORE INFORMATION

Canopy management factsheet

Cereal growth stages guide

Advancing the management of crop canopies.

23 GRDC. (2009). Canopy management Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2010/02/canopy-management

Crop desiccation/spray out

Not applicable for this crop.

Harvest

Key messages

- Harvesting and storage management for triticale is generally similar to that for wheat. However, spring triticale for grain is a late-maturing crop, and is also more susceptible to sprouting conditions at harvest than wheat.
- Preferred harvest moisture to reduce damage due to heating caused by moulding is 14% or less. [1]
- For best returns aim to harvest crops at 12% moisture or less, produce grain with a minimum test weight of 65 kg/hl and minimise other cereal grain contaminants.
- One of the drawbacks of triticale grown for grain is that it is prone shattering.
- Combine settings should be set similar to those for wheat, with care taken to slow the cylinder speed to minimise grain cracking and splitting. [2]
- Some varieties are difficult to thresh cleanly without either leaving intact head sections in the grain sample or causing grain cracking through tight concave settings. Conversely, some varieties are prone to shedding under windy conditions.

12.1 Harvesting issues

One of the drawbacks of triticale grown for grain is that it is prone shattering (Photo 1). There is a spot about a quarter to a third of the way down from the tip on the rachis that is very weak. [3]

Photo 1: *Shattered cereal grain.*

Source: National Plant Germplasm System (USDA/ARS)

1 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

2 Alberta Agriculture and forestry. (2016). Triticale crop production. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

3 Alternative crops – Triticale in the US.

Triticale varieties vary strongly in thresh-ability. Some varieties are difficult to thresh cleanly without either leaving intact head sections in the grain sample or causing grain cracking through tight concave settings. Conversely, some varieties are prone to shedding under windy conditions.

Most triticale varieties have inverted heads at maturity which shed rain and therefore make the crop less liable to sprouting at maturity. This can be especially important in regions where storms can delay harvesting.

The level of carryover (hard seed) self sown plants which occurs after a triticale crop appears to be higher than with other winter cereals. No data exists concerning any varietal differences in hard seed levels but especially where some seed shedding has occurred this will need careful management. [4]

Triticale grain generally matures later than wheat or rye and has a higher protein content which makes it a good home grown feed option. Attention must be paid to ensure that ergot levels are less than 0.1 per cent. Newer varieties have fewer ergot problems. Combining standing grain rather than windrowing first is advisable because triticale is more susceptible to sprouting in the windrow than wheat. [5]

12.2 Windrowing

Windrowing or swathing involves cutting the crop and placing it in rows held together by interlaced straws, supported above the ground by the remaining stubble (Photo 2). It can be considered as an option where:

- the crop is uneven in maturity, or the climate does not allow for rapid drying of the grain naturally
- there is a risk of crop losses from shedding and lodging

High yielding crops may gain more from windrowing than low yielding crops. Generally, crops expected to yield less than 2 t/ha should not be windrowed. Picking up windrowed cereals is significantly slower than direct heading because of the large volume of material.

If the crop is too thin or the stubble too short to support the window above the ground, the crop should not be windrowed. Heads on the ground may sprout and attempts to pick up heads that are lying close to the soil surface will pick up soil. [6]

4 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

5 Albert Lea Seed. Triticale http://www.alseed.com/UserFiles/Documents/Product%20Info%20Sheets-PDF/Basics%20Triticale-2010.pdf

6 G Troup (2016) Oats: harvesting, swathing and grain storage, Swathing. DAFWA, https://www.agric.wa.gov.au/oats/oats-harvesting-swathing-and-grain-storage?page=0%2C1

Photo 2: *Directing chaff into a narrow windrow using a custom-made chute.*

Source: GRDC

12.2.1 Timing

Windrowing can begin when grain moisture content is below 35%—when grain is at the medium dough stage, hard but can still be dented with the thumbnail.

- It is better to windrow early to prevent losses from shedding and lodging, but not when the ground is wet after rain.
- Avoid windrowing too early as the grain is not fully developed and will result in small pinched grain.
- Although it may be easier to windrow later, the windrows of a ripe crop may not interlock well enough to withstand disturbance from strong wind. [7]

12.2.2 Cutting

- Cut across the sowing direction, or at 45 degrees for crops with wider row spacing, so the windrow sits-up on the stubble. Windrowing is not recommended for paddocks where the crop row spacing is over 25 cm.
- Avoid placing windrows in the same location each year so nutrients are not concentrated in one place.
- Windrow size or width of cut should match header capacity. A double-up attachment to the windrower or placing two windrows side by side requires a larger capacity header and concentrates the residue in a narrow band within the paddock.
- Cutting height should be adjusted to keep sufficient straw on the head to hold the windrow together (minimum 30 cm) and sufficient stubble height to support the windrow.
- Start the cutting height at 10–20 cm above the ground (one-third crop height) and adjust to produce an even windrow with well-interlaced straws that sit above the ground. This allows good air circulation and rapid drying should rain occur. [8]

7 G Troup (2016) Oats: harvesting, swathing and grain storage, Swathing. DAFWA, https://www.agric.wa.gov.au/oats/oats-harvesting-swathing-and-grain-storage?page=0%2C1

8 G Troup (2016) Oats: harvesting, swathing and grain storage, Swathing. DAFWA,https://www.agric.wa.gov.au/oats/oats-harvesting-swathing-and-grain-storage?page=0%2C1

12.2.3 Harvesting the windrow

Harvesting of the windrowed crop must be completed as soon as possible, ideally within 10 days of windrowing.

- If left too long and subjected to long periods of wetting (more than 25 mm of rain over 4–8 days), grain may sprout and become stained. The windrow may also become contaminated with bronze field beetle.
- When the windrow is picked up, the reel should be rotating slightly faster than ground speed, but not fast enough to knock the heads off the stems.
- The conveyor canvas should be revolving sufficiently fast to prevent the crop material banking up.
- Rows pick up best when the header follows the direction of the windrow (heads first).

One of the major sources of contamination in windrowed cereals is the stubble being torn out during the windrowing operation. This generally occurs when the windrower is operated at too high a ground speed or when trying to windrow when the straw is tough due to it being cool or damp. [9]

MORE INFORMATION

Setting up at harvest for narrow windrow burning

12.3 Harvest timing

Harvesting and storage management for triticale is generally similar to that for wheat. However, spring triticale for grain is a late-maturing crop, and is also more susceptible to sprouting conditions at harvest than wheat.

In dryland conditions, straight cutting of triticale is recommended where conditions allow. This is because straight cutting for grain can help reduce losses from pre-harvest sprouting, which triticale is much more susceptible to than is wheat.

Combining at 14% grain moisture is considered dry for triticale (Photo 3). In Australia is it recommended that triticale be stored at 10% moisture content.

Photo 3: *Harvesting of triticale grain with dry moisture content.*

Source: GRDC

Moisture content lower than 13.5% is very desirable, as most moulds and insects tend to be inactive below this moisture level.

9 G Troup (2016) Oats: harvesting, swathing and grain storage, Swathing. DAFWA.https://www.agric.wa.gov.au/oats/oats-harvesting-swathing-and-grain-storage?page=0%2C1

For best returns aim to harvest crops at 12% moisture or less, produce grain with a minimum test weight of 65 kg/hl and minimise other cereal grain contaminants.

Kernels with moisture content up to 20% can be harvested and, if properly dried, will not lose quality. If drying triticale grain, maximum desirable temperatures are:

- 40°C for seed.
- 65°C for commercial grain.

Optimum harvest stage for forage is when the plant is at the flag leaf or boot stage before head emergence. Protein content at this stage will vary between 14–19%. Generally, forage yields and palatability will be higher than for either wheat or rye. [10]

One study found that triticale dry matter yield was higher and more nutritious when harvest was shifted from early heading to milk dough stage. [11]

For more information on storing triticale, see Section 13: Storage.

In high fertility situations, lodging can occur. Under such conditions, plan to harvest early. [12]

Lodging

Lodging occurs when portions of the crop 'fall over' due to strong wind, and occasionally in very high yielding crops and/or varieties with weak stems.

The lodged plants will then begin to deteriorate in nutritive value, and the grain may even begin to sprout if advanced enough in its formation (hard dough stage).

If possible, harvest the crop within days before its nutritive value deteriorates too much and mould and deleterious bacteria build-up occurs. Travelling in the opposite direction to the lodged plants will ensure less difficulty in the harvest operation and minimal losses.

Crops lodged for some period of time can be a problem. If the harvester travels in the opposite direction to which the plants are lodged, its nutritive value will be decreased due to harvesting the decaying plants. This decaying plant material will also adversely affect the fermentation process. [13]

Harvesting a frosted crop

Harvesting a frosted crop brings another layer of complexity to an already busy time of year. Some of the complications are limited to this season's harvest; whilst others have ramifications for next season's crop.

Considerations for harvest;

- Frost damage varies across the landscape in severity and scale in some areas.
- Better yielding paddocks and crops should be harvested first.
- Frosted crops are difficult to thresh due to higher residual sugars and lower grain volume. Despite lower tonnages, daily harvest maintenance and regular clean down remain important to minimise machinery fatigue and fire risk in these difficult harvesting conditions.
- Grain quality may also be compromised depending on the frost timing. Frost affected grains usually have a lower hectolitre weight and higher screenings. Adjusting header settings and/or grading can be beneficial but check the feasibility first.

Considerations for next season;

- Frosted stubble can rot off at ground level and be difficult to seed into. To minimise trash flow problems stubbles may have to be cut low.

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10 Alberta Agriculture and forestry. (2016). Triticale crop production. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

11 McGoverin, C. M., Snyders, F., Muller, N., Botes, W., Fox, G., & Manley, M. (2011). A review of triticale uses and the effect of growth environment on grain quality. *Journal of the Science of Food and Agriculture*, *91*(7), 1155–1165.

12 Albert Lea Seed. Triticale http://www.alseed.com/UserFiles/Documents/Product%20Info%20Sheets-PDF/Basics%20Triticale-2010.pdf

13 Agriculture Victoria. (2008). Harvesting Forage Cereals. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/harvesting-forage-cereals

- Given the residual nutrients in frosted crops there may be a risk of windrow effects.
- Evaluating weed seed burdens and wind erosion risk will help determine the best course of action.
- If keeping seed for next season, it is important to source seed from least-affected areas to maximise establishment. Seed quality can be tested closer to seeding by DAFWA Diagnostic Laboratory Services for a small charge. [14]

12.3.1 Harvesting triticale for silage

The cutting and subsequent storage of triticale forage for silage is similar to that of any small-cereal forage. The harvest date of triticale for silage is very important. As plants develop beyond the boot stage and into early grain fill, the protein and energy levels drops while the fibre level rapidly increases. Although there is a general increase in dry-matter yield as the crop matures, the increased yield is more often offset by the reduction in forage quality. Consequently, the best time to cut triticale for silage is in the boot to early-heading stage. [15]

Timing of harvest should consider the following:

- end use of the silage; i.e. for animal production vs. maintenance rations
- weather conditions at harvest
- soil types and soil moisture conditions at harvest
- if spring sowing, when the follow up pasture is to be sown
- if double cropping, when the follow-up crop needs to be sown
- availability of suitable harvesting machinery
- affect on dry matter yield

Cereals can be harvested at two stages:

1. Flag leaf/boot - early ear emergence stages
2. Soft dough stage.

Triticale is particularly well adapted for high forage yield production on heavily manured fields. Harvesting protocols and timing must be adjusted to accommodate the differences between triticale and barley in these situations. In high productivity systems where lodging is a problem, triticale should be compared to semi-dwarf barley, which also has special adaptation to high fertility conditions.

When using triticale for silage, it has been recommended that the optimum time for harvest was at the soft dough stage in order to best balance potential quality and yield. [16]

MORE INFORMATION

When to cut forage cereals

Triticale for silage

12.4 Harvest equipment

Harvester settings should be set similar to those for wheat, with care taken to slow the cylinder speed to minimize grain cracking and splitting (Photo 4). [17]

Seed size can be of concern when harvesting triticale. Triticale varieties generally have a large seed and a large embryo with an elongated beak compared to bread wheat. Caution must be taken to ensure that any mechanical harvesters, such as modern combines, are appropriately set so that there is no damage to the embryo. Embryo damage and seed cracking can have a significant impact on seed viability during storage. This can be a problem since many triticale varieties are hard to thresh compared to wheat and rye.

In triticale without the wheat rachis, threshing frequently results in incomplete seed and chaff removal from the spike, and breakage may occur at the rachis nodes. In

14 DAFWA. (2016). Harvesting a frosted crop. https://www.agric.wa.gov.au/frost/harvesting-frosted-crop-0

15 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

16 Alberta agriculture and forestry. (2016). Triticale for Silage. www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10569

17 Alberta Agriculture and forestry. (2016). Triticale crop production. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/fcd10571

the wheat rachis types, breakage does not occur. Improvements in threshing will be an excellent improvement where mechanical threshing equipment is not readily available or economically feasible. [18]

Harvest triticale as you would wheat, with a combine. The combine speed should be slightly slower than for harvesting wheat. It is possible to windrow triticale before combining, but it is likely to begin sprouting in the windrow, so growers are advised to direct-combine if possible. [19]

Photo 4: *Triticale being harvested.*

Source: Kaspar T in MCCC

Recent trials have found there is a 10% lift in header efficiency for every 10 cm increase in harvest height. The trials in the HRZ compared three harvest heights – 15 cm, 30 cm and 50 cm – in wheat and barley.

Harvesting low is done to reduce stubble loads to manageable levels and achieved by baling or burning the windrows, or simply spreading trash and straw as evenly as possible across the header windrow.

Harvesting low and treating weed seeds also has the potential to reduce the soil weed seedbank over time, which can assist with weed control and herbicide resistance management.

The work in 2014 has shown how much slower harvesting is at a 15 cm height and the additional fuel consumption required. When increasing the height to 50 cm it was found that harvesting was around 25% faster than 30 cm. A rule of thumb is a 10% efficiency increase for every 10 cm of harvest height. If a 100ha crop is harvested at 15 cm it will take about 20% more time to harvest than a crop cut at 30 cm, or 38% more time than if it had been harvested at 50 cm. [20]

Ensure that all equipment is clean and free from potential contaminants to the harvested grain (Photo 5).

18 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org.

19 UVM. Triticale. Northern grain growers. http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

20 Lawson A. (2015). Ground Cover Issue 118: Header efficiency increases with harvest height. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-118-Sep-Oct-2015/Header-efficiency-increases-with-harvest-height

Photo 5: *Cereal harvest underway. It is important to clean all equipment prior to and after harvesting.*

Source: Creative Commons

12.5 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.
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. [21]

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. [22]

With research showing an average of 12 harvesters burnt to the ground every year in Australia (Photo 6), 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. [23]

21 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

22 NSW Rural fire Service. Farm firewise. NSW Government, http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161

23 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

Photo 6: *GRDC figures show that there are 1000 combine harvester fires in Australia each year.*

Source: Weekly Times

12.5.1 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 1).

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 35°C 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 1: *Grassland fire danger index guide.*

Source: CFS South Australia

PODCAST

LISTEN: 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

MORE INFORMATION

Grain Trade Australia – Cereal Rye and Triticale trading standards 2016/2017

12.6 Receival standards

Stay up to date with the Grain Trade Australia (GTA) national grain receival standards. The GTA Trading Standards are a critical tool for anyone purchasing, selling, trading, broking or operating in the commercial grain industry. The GTA Trading Standards cover all grains, oilseeds, pulses and other related commodities.

For Triticale, there is no minimum variety specification and a load may be delivered with a varietal mix at any level.

Any variety is eligible for delivery into the Triticale grade.

Table 1: *Triticale receival standards.*

These Receival standards are current as at 1/09/2016	TRI1
Infratec	
Protein	No Limit
Moisture Content (maximum)	13
½ Litre (Weight)	
Weight (minimum kg/hl)	65.00
Weight (minimum grams)	325.0
½ Litre (Count)	
Type 1 Seeds (maximum)	
Doublegees	1
Lupins	1
Saffron Thistle	1
Variegated Thistle	1
Field Peas	1
Safflower	1
Sunflower	1
Sappy Green Grains/Sappy Green Material (maximum)	10
Storage Mould/ Bin Burnt /Heat Damaged Grains (maximum)	1
Type 2 Seeds (maximum) Barley, Oats, Drake Seed, Black/ Brown or Wild Oats, Radish Pods, etc.	50
Field Insects (maximum) Whole bodies, live or dead, Grasshoppers, Ladybirds, Woodbugs, Pea Weevils, Native Weevils, Bronzed Field Beetles and Army Worms.	15 of each
Whole Snail Shells (maximum) Live or dead, fragments acceptable.	1
Sprouted (maximum)	10
1 Level BPM	
Speargrass (maximum)	5
Type 3 Seeds (maximum) Wheat and Cereal Rye	10
% by Weight	
Screenings/Unthreshed Heads Combined (maximum)	6

These Receival standards are current as at 1/09/2016	TRI1
½ Litre after Screening	
Ryegrass Ergot (maximum)	5 cm
Dead Grain Insects (maximum)	10

Source: GIWA

12.7 Harvest weed seed management

Controlling weeds after harvest may be more difficult in southern regions as there can be several months of good growing conditions for weeds

In the southern cropping region's high rainfall zone (HRZ), 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?

Southern Farming Systems (SFS) is answering these questions through its Grains Research and Development Corporation-funded HRZ harvest weed seed control (HWSC) project. Paddock-scale trials will demonstrate to growers the suitability and effectiveness of a number of HWSC measures, using commercial equipment to highlight the potential of these management practices to complement large scale trials.

Trial plots have been established at SFS's Lake Bolac site in western Victoria and in Tasmania. [24]

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. [25]

12.7.1 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

Key points:

- Herbicide resistance is rapidly becoming more widespread and growers need to act to save what effective herbicides that are left. Harvest weed seed control is a suite of tools to combat this and narrow windrow burning the cheapest and easiest to implement.
- Narrow windrow burning (WB) has proven to be successful in other regions on key weeds such as annual ryegrass and wild radish

MORE INFORMATION

IWM manual section on harvest weed management.

24 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

25 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 narrow windrow burning.

DAFWA – Burning windrows for weed management- Factsheet

Windrow burning – tips from the experts

The nuts and bolts of efficient and effective windrow burning

IWM manual section on chaff carts

Over the Fence west: Chaff tramlining tackles weeds.

IWM manual section on bale direct systems

IWM manual section on Harrington seed destructor

Lesson and optimism after first iHSD harvest

New data on the integrated Harrington seed destructor and its efficacy on a broad range of weed species, including fleabane and sow thistle

- There is no reason to doubt its effectiveness here on those same key weeds. WB effectiveness on other species that shed seed early such as wild oats may be less reliable.
- Successful WB is not hard and may take some practice to become an expert. Following some simple suggestions may help avoid mistakes
- The biggest factor to success - you must cut the crop low, less than 15 cm
- There are some downsides to WB such as selection for weeds resistant to WB, negative impacts on fallow efficiency or nutrient implications but these must be weighed up against the positive for weed control and resistance management. [26]

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.

Chaff carts

Chaff carts are towed behind headers during harvest to collect the chaff fraction (Photo 7). Collected piles of chaff are then either burnt the following autumn or used as a source of stock feed.

Photo 7: *Chaff cart in action*

Photo: A. Storrie

Chaff carts will collect and remove up to 85% 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. [27]

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).

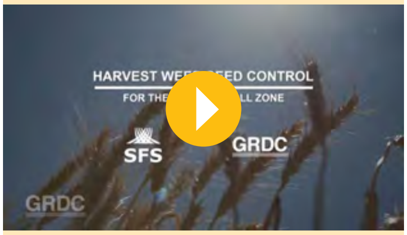
26 Street M. (2015). The nuts and bolts of efficient and effective windrow burning. GRDC Update papers. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/The-nuts-and-bolts-of-efficient-and-effective-windrow-burning

27 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

VIDEOS

WATCH: iHSD

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.

Integrated Harrington Seed Destructor

Developed as a trail behind unit, the Integrated Harrington Seed Destructor (iHSD) [28]system comprises a chaff processing cage mill, chaff and straw delivery systems. The retention of all harvest residues in the field reduces the loss and/or banding of nutrients and maintains all organic matter to protect the soil from wind and water erosion, as well as reducing evaporation loss when compared with windrow burning, chaff carts and baling.[29]

The iHSD, which renders seeds non-viable by collecting and impacting the chaff as it mexits the harvester, can very effective, depending on seed species. [30]

Photo 8: *Integrated Harrington Seed Destructor.*

Source: GRDC

28 http://www.ihsd.com/

29 GRDC Integrated weed management hub. Section 6: Managing weeds at harvest. https://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

30 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

- Long term on-farm storage of triticale will be a problem unless the storage facility is sealed silos.
- Triticale grain is softer than wheat and barley grain. Soft grain is more prone to attack from weevils and other grain storage insects.
- Maintain grain at low (<10%) moisture content to minimise insect infestation.
- Fumigation prior to storage in sealed silos is effective in reducing the risk of insect damage when storing triticale. [1]
- Storing grain at levels less than 12% does not eliminate the need for treating it with insecticide, however it does avoid spoilage from mould and fungus growth. [2]
- It is recommended to use a protectant when storing triticale post-harvest. Aeration is recommended when storing triticale. [3]

Drying and storage of triticale is similar to wheat or rye, however, triticale is extremely sensitive to grain insect infestations, far more so than wheat, and even more so than barley (Photo 1). Care must be taken in regard to long term storage of triticale grain.

Photo 1: *Rust-red flour beetle on cereal grain.*

Source: DAFWA

Triticale has a very soft-textured kernel and may be subject to damage from insect infestation during the storage process. Triticale should be stored in dry, well-ventilated area to reduce potential damage from moisture. Preferred harvest moisture to reduce damage due to heating caused by moulding is 12% or less. [4]

Triticale should be less than 12% moisture when stored, but the lower the moisture content the better. Storing grain at levels less than 12% does not eliminate the need for treating it with insecticide, however it does avoid spoilage from mould and fungus growth. [5]

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

2 Waratah Seed Co. Ltd. (2010) Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

3 Waratah Seed Co. Ltd. (2010) Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

4 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org

5 Waratah Seed Co. Ltd. (2010) Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

It is recommended to use a protectant when storing triticale post-harvest. Aeration is recommended when storing triticale. [6]

When storing triticale it is critical to pay attention to:

- Truck, auger, silo or storage bin hygiene
- Grain temperature
- Grain moisture content
- Grain insecticide treatment
- Monitoring the storage regularly.

Seek professional advice about storing triticale to reduce the risk of insect infestation and significant grain losses.

Newer varieties are generally of a harder seed type but they still require careful grain protection during storage. Maximum moisture content for triticale grain storage is 12% and aeration cooling is one way to reduce insect problems. Chemical protectants are also usually needed in triticale storage. [7]

Triticale may also fungal development. Some triticales show high levels of enzymatic activity, even in the absence of visual sprouting or spike wetting. This greater than normal enzymatic activity in sprouted grain may promote fungal development during storage or may have deleterious effects on the food-processing characteristics of grain. [8]

13.1.1 Considerations for WA growers

Whether storing harvested grain for future marketing or crop planting, key factors to consider are silo hygiene and aeration, insect and pest control, grain quality and economics.

Without attention to detail, there are risks of:

- Grain quality issues in some areas that experienced a wet start to harvest this year
- Development of resistant stored grain insect pests in WA

Importance of storage facility hygiene and preparation

WA is the only Australian state able to export its entire grain harvest without the use of contact insecticides.

Local research shows that correct grain storage hygiene and aeration practices can supress stored grain insects and pests and maintain grain quality to boost seed viability for subsequent crop plantings.

Grain residue in storage facilities needs to be removed, as it provides ideal breeding sites for grain pests. Only a handful of grain is enough to maintain a viable insect population.

The Department of Agriculture and Food, Western Australia (DAFWA) says treating silos with products such as diatomaceous earth (DE) dust (e.g. Dryacide®) before storing grain is valuable.

It suggests growers be aware of withholding periods if treating the inside of empty silos with an insecticide, such as Malathion dust/liquid, to provide residual control before grain is loaded into the store.

It is illegal to apply protectants other than Malathion and Dryacide® to grain in WA, except if it is to be used for seed.

Before storing grain, gas-tight sealable silos should also be tested for any gas leaks and pressure relief valves filled with light hydraulic oil.

6 Waratah Seed Co. Ltd. (2010) Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

7 Jessop RS, Fittler M. (2009). Triticale production Manual – an aid to improved triticale production and utilisation. http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

8 Mergoum, M., & Macpherson, H. G. (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Org..

For a silo to meet the Australian Standard 2628 – covering suitability to fumigate with phosphine – it must be subjected to a five minute, half-life pressure test when newly installed and a three minute half-life pressure test if already established.

If it meets the pressure test requirements, it will hold phosphine gas and other fumigants at a concentration high enough and for long enough to kill insects at all life stages (eggs, larvae and pupae).

Reducing reliance on phosphine fumigations

Phosphine gas can only be used for grain that is stored in tested gas-tight silos and it is highly effective - but must be held at a lethal concentration for 7–10 days to kill insects at all growth stages.

There have been six documented detections of grain storage insects with strong phosphine resistance in WA (all of which have been eradicated), highlighting the need for correct fumigation and less reliance on this fumigant.

DAFWA says poor fumigation will result in only adults being killed and numbers building-up again from infestations from immature eggs and pupae.

It says in poorly maintained seed and storage silos, inadequate fumigation time promotes the selection of phosphine resistant individuals that survive and multiply.

Detecting phosphine resistant grain pests early will make eradication possible.

A free resistance test for grain pests is available from DAFWA - contact Nuccia Eyres or David Cousins from the Department's stored grain insect group: 08 9368 3920.

GRDC's Grain Fumigation Guide Fact Sheet provides advice on application rates, handling advice, where and when to apply and tips on gas venting.

Storing high moisture and sprouted grain

Typical harvest temperatures of 25–30°C and grain moisture content of more than 13–14% provide ideal conditions for mould and insect growth during storage.

The key to dealing with high moisture and sprouted grain is to act quickly and effectively.

GRDC's Dealing with high moisture grain Fact Sheet outlines a range of management strategies, including:

- Daily monitoring of grain moisture and temperature for early detection of any mould or insects
- Blending high and low moisture grain evenly to achieve an average 12.5% moisture and aerating
- Using aeration cooling for grain with moderate moisture (up to 15% moisture content) for up to two months until drying equipment is available
- Using aeration drying in storage facilities at airflow rates of more than 15 litres per second per tonne
- Potentially using dedicated batch or continuous flow dryers for high moisture grain before storage.

Sprouted grain can be retained for seed, but it is best to use grain with a falling number of more than 150 and only retain this seed for one summer – as its ability to germinate will deteriorate faster than sound grain. There is also some evidence of reduced seedling vigour.

The South East Premium Wheat Growers Association (SEPWA) has produced booklets called '*Dealing with a Difficult Harvest*' and '*The WA Guide to High Moisture Harvest Management'* and these recommend minimal handling and using cool, aerated conditions when storing sprouted grain.

Aerating stored grain

A combination of good hygiene and well-managed aeration cooling during grain storage offers harvest flexibility, more marketing opportunities, better control of grain quality and potentially higher viability of seed grain for subsequent plantings.

Aeration of stored grain creates a low temperature in the silo to prevent mould, inhibit insect development, maintain seed viability and reduce grain moisture.

Insects rely on the environmental temperature for body warmth and will breed faster in warmer conditions.

If the temperature is below 20°C, they will produce less progeny in the storage period. But to stop reproduction, grain temperatures need to be below 14°C.

Through its Grain Storage Extension Project, GRDC has produced a Grains Industry Guide to Aerating Stored Grain that outlines cooling, drying and equilibrium tables and a Fact Sheet.

Economics of grain storage

Grain storage is a long term investment and its viability is unique to every grower.

A cost benefit analysis is useful to compare the expected returns from grain storage versus expected returns from other farm business investments.

A comparison of the cost of storing grain on farm versus paying a bulk handler to store it is also worthwhile.

Observations made by the GRDC Grain Storage Extension Project team indicate growers who are taking a planned approach to on-farm grain storage and are doing it well are being rewarded for it.

They say grain buyers are seeking out growers with well-designed storage systems that enable delivery of insect-free, quality grain without delay.

An example of this in WA is the Candeloro family, who store 85 per cent of grain (including wheat, canola and barley) produced annually on their 8000ha Toodyay property in state-of-the-art storage and handling facilities that have a capacity of 38,000 tonnes.

The aim is to capture premium prices by suppling quality grain direct to end users and their customers include Inghams Enterprises, Milne Feeds and West Coast Milling.

The Candeloros say another big advantage of an on-farm storage system is the opportunity to back-load trucks carting grain with fertiliser and lime, which spreads haulage costs across the grain enterprise. [9]

13.2 How to store product on-farm

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 could be the 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 reason 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

9 Williams M. (2015). Tips and tools for grain storage this harvest. https://grdc.com.au/news-and-media/news-and-media-releases/west/2015/10/tips-and-tools-for-grain-storage-this-harvest

- 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 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. [10]

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 tonnes up to 3000 tonnes Up to 25 year plus service life Simple in-loading and out-loading Easily administered hygiene (cone base particularly) Can be used multiple times in-season	Requires foundation to be constructed Relatively high initial investment required Seals must be regularly maintained Access requires safety equipment and infrastructure Requires an annual test to check gas-tight sealing
Non-sealed silo	Easily aerated with fans 7–10% cheaper than sealed silos Capacity from 15 tonnes up to 3000 tonnes Up to 25 year plus service life Can be used multiple times in-season	Requires foundation to be constructed Silos cannot be used for fumigation – see phosphine label Insect control options limited to protectants in eastern states and and dryacide in WA. Access requires safety equipment and infrastructure

10 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 intial cost Can be laid on a prepared pad in the paddock Provide harvest logistics support Can provide harvest segregation options Are all ground operated Can accommodate high-yielding seasons	Requires purchase or lease of a 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	Aerating 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

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 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.

> *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.* [11]

Agronomist's view

11 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

13.2.1 Silos

Triticale is very prone to damage from insects during storage due to its soft kernel. To minimise insect attack, the grain should be stored at less than 10% moisture, preferably in sealed silos (Photo 2). Treat the grain as it enters the silo and then check regularly (2–3 months) for reinfestation by grain insects.

Photo 2: *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. [12]

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.

12 Francis J. (2006). An analysis of grain storage bags, sealed grain silos and warehousing for storing grain.

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 seven days or 200ppm 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 5 years. A Grains Research and Development Corporation survey during 2010 revealed that only 36% of growers using phosphine appliedit 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 parts per million (ppm) gas concentration for 7 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. [13]

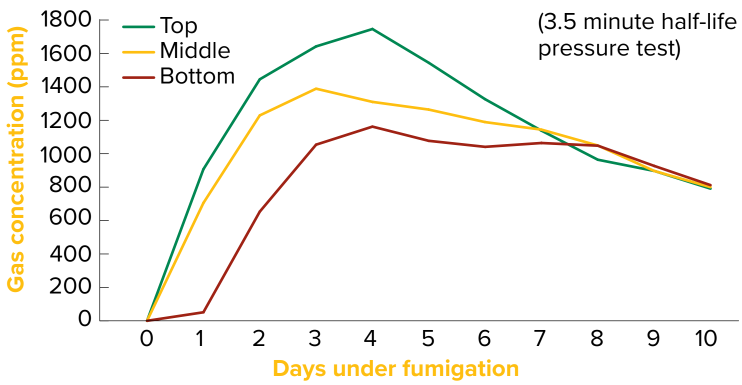


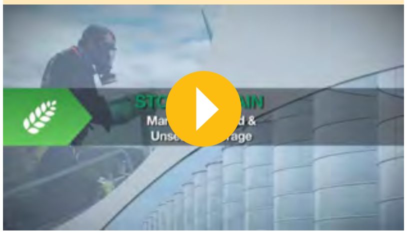
Figure 1: *Gas concentration in gas-tight silo.*

Source: GRDC

13 P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. GRDC Fact Sheet, September 2010, http://storedgrain.com.au/pressure-testing/

VIDEOS

WATCH: Stored grain: Managing sealed and unsealed storage.



MORE INFORMATION

Fumigating with phosphine, other fumigants and controlled atmospheres

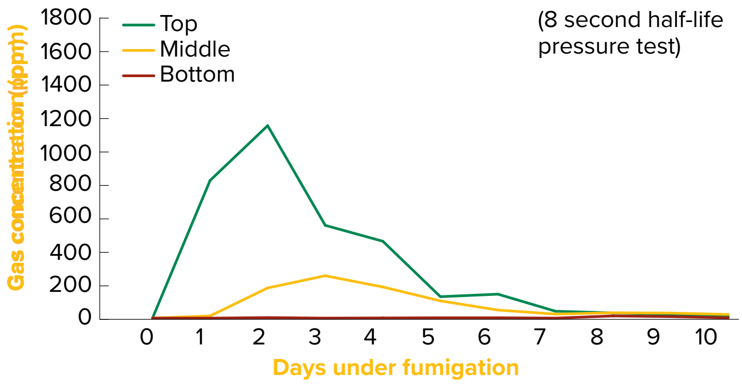


Figure 2: *Gas concentration in non-gas-tight silo.*

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.

13.2.2 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 cereal grain and are filled and emptied using specialised machinery (Photo 3). 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.

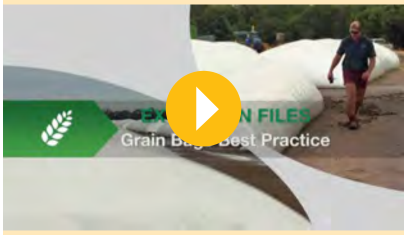
Potential advantages of using grain storage bags as a method for grain storage include the low capital set up costs, improved harvest management, less harvest stress, reduced harvest freight requirements, minimal cost in occupational health and safety (OH&S) requirements, reduced grain insecticide requirements 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. [14]

14 Francis J. (2006). An analysis of grain storage bags, sealed grain silos and warehousing for storing grain.

VIDEOS

WATCH: Grain bags best practice.



WATCH: Extension Files: Grain bags – a grower's perspective.

Photo 3: *A 100m bag can be filled in 30 minutes with a constant supply of grain.*

Source: StarTribune

13.2.3 Hygiene

Always thoroughly clean trucks, augers and storages prior to storing triticale. Dust and grain from previous years grain should all be totally removed to avoid rapid infestation with stored-grain insects. [15]

13.2.4 Insecticide treatment

There are three options for insecticide treatment:

- Chemical protectant: applied directly to the grain; used to treat uninfested grain; protect for three to nine months depending on product
- Fumigation: only in a sealed silo; fumigant in tray or sachet in head-space of silo not in contact with grain; residue free; minimises insect resistance to chemicals
- Aeration cooling: residue free; lowers temperature of grain; reduces potential of insect infestation.

13.2.5 Monitoring stored grain

Check the grain regularly during storage for signs if grain insect activity and be prepared to deal with an infestation if it occurs. [16]

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 4).
- 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. [17]

15 Waratah Seed Co. Ltd. (2010) Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

16 Waratah Seed Co. Ltd. (2010) Triticale: planting guide. http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

17 Plant Health Australia. (2015). Monitoring stored grain on farm.

Photo 4: *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

13.2.6 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's 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's 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 cost, 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's difficult to put an exact dollar value on each of the potential benefits and costs, a calculated estimate will determine if it's 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've 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 are seeing around Australia, the growers who are taking a planned approach to on-farm grain storage and doing it well are being rewarded for it. 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. [18]

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 eg 25yrs	$6.20
Opportunity cost on capital	Capital cost $/t x opportunity or interest rate eg 8% / 2	$6.20
Total fixed costs	Sum of fixed costs	$12.40

18 Warrick C. (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

MORE INFORMATION

GRDC Economics of on-farm grain storage, cost benefit analysis.

VIDEOS

WATCH: Over the Fence: On-farm storage delivers harvest flexibility and profit.

WATCH: Stay safe around grain storage.

Financial gains from storage		Example $/t
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	
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

13.3 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. [19]

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)*.

19 GRDC Stored Grain Information Hub. Northern and Southern Regions Grain Storage Pest control guide. http://storedgrain.com.au/pest-control-guide-ns/

Another dozen or so beetles, psocids (booklice) and mites are sometimes present as pests in stored cereal grain.

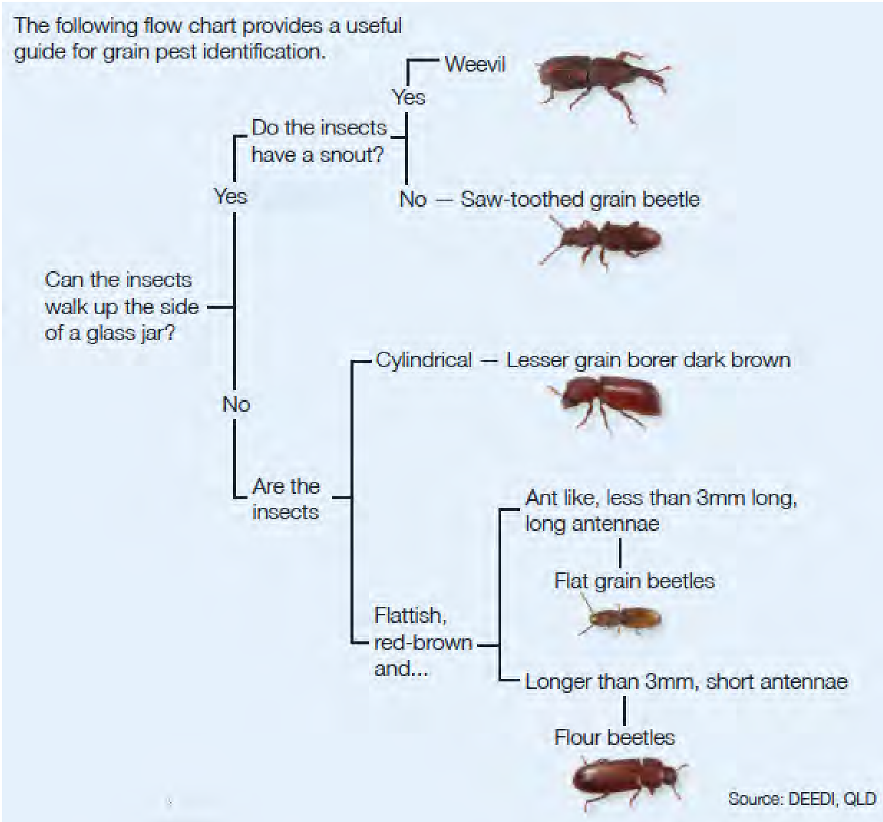


Figure 3: *Identification of common pests of stored grain.*

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 using 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 using 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 days to 28 days.

13.3.1 Monitoring grain for pests

Damage by grain insect pests often goes unnoticed until the grain is removed from the 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 5).

MORE INFORMATION

Western region – stored grain pest identification

DAFWA – Insect pests of stored grain

MORE INFORMATION

GRDC Stored grain pests; the back pocket guide

VIDEOS

WATCH:GCTV2: Grain Storage Insect ID.

- 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.
- 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 three weeks prior to sale to allow time for treatment if required. [20]

Photo 5: *A 2 mm mesh sieve will separate insects from grain.*

Source: Plant Health Australia

13.3.2 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 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
- Spilt grain around grain storages
- Equipment and rubbish around storages
- Seed grain
- Stockfeed grain

20 Plant Health Australia. (2015). Monitoring stored grain on farm.

Successful grain hygiene involves cleaning all areas where grain gets trapped in storages and equipment (Photo 6). Grain pests can survive in a tiny amount of grain, so any parcel of fresh grain through the machine or storage becomes infested.

Photo 6: *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 1000 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, a follow-up wash-down removes grain and dust left in crevices and hard-to-reach spots (Photo 7). Choose a warm, dry day to wash storages and equipment so 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 left-over 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 7: *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 81).

Agronomist's view

Photo 8: *Concrete slab under silo makes cleaning up spilled grain much easier.*

Source: GRDC

VIDEOS

WATCH: Grain Silo Hygiene.

13.3.3 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).

Photo 9: *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.

13.3.4 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.

Chemicals used for structural treatments do not list the specific use before storing pulses on their labels and MRLs in pulses for those products are either extremely low or nil. Using chemicals even as structural treatments risks exceeding the MRL so is not recommended.

Using diatomaceous earth (DE) as a structural treatment is possible but wash and dry the storage and equipment before using for pulses. This will ensure the DE doesn't discolour the grain surface. Diatomaceous earth is an amorphous silica commercially known as Dryacide® and 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. [21]

MORE INFORMATION

Hygiene and structural treatments for grain storages.

13.3.5 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 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 10).

21 GRDC Stored Grain information hub. Storing Pulses. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/07/grain-storage-fact-sheet-storing-pulses

Photo 10: *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 3).

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 3). 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. [22]

Table 3: *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
1800	2.60

13.3.6 Fumigation

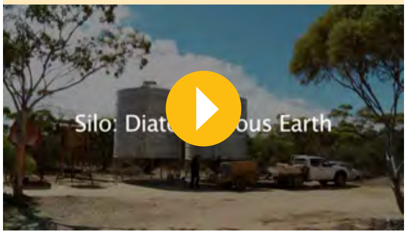
There are a number of chemical control options for the control of grain pests in stored cereals (Table 5).

Photo 11: *Resistance and efficacy guide for stored grain insects. Before applying, check with your grain buyers/bulk handlers and read labels carefully.*

22 Pulse Australia (2013) Northern chickpea best management practices training course manual —2013. Pulse Australia Limited.

VIDEOS

WATCH: Applying diatomaceous earth dust.



MORE INFORMATION

GRDC Grain Storage Fact Sheet: Hygiene and Structural Treatment for Grain Storages.

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	Effective control	Effective control	Effective control	Effective control	High-level resistance	Effective control	Not registered
Sulfuryl fluoride (ProFume®)[10]	1	Effective control	Effective control	Effective control	Effective control	Effective control	Not registered	Not registered
Grain protectants—applied postharvest. Poor adult control if applied to infested grain								
Pirimiphos-methyl (Actellic 900®)	nil[2]	Not registered	Effective control	Effective control	Resistance widespread	Effective control	Not registered	Resistant species likely to survive
Fenitrothion (Fenitrothion 1000®)[4, 7]	1–90	Not registered	Effective control	Effective control	Resistance widespread	Not registered	Not registered	Resistant species likely to survive
Chlorpyrifos-methyl (Reldan Grain Protector®)[5]	Nil[2]	Resistance widespread	Effective control	Effective control	Resistance widespread	Not registered	Not registered	Resistant species likely to survive
'Combined products' (Reldan Plus IGR Grain Protector)	Nil[2]	Resistance widespread	Effective control	Effective control	Effective control	Not registered	Not registered	Resistant species likely to survive
Deltamethrin (K-Obiol®)[10]	Nil[2]	Effective control	Effective control	Resistance widespread	Effective control	Effective control	Not registered	Not registered
Spinosad and Chlorpyrifos-methyl (eg Conserve On-Form™)[9]		Effective control	Effective control	Effective control	Effective control	Effective control	Not registered	Not registered
Diatomaceous earth, amorphous silica—effective internal structural treatment for storages and equipment. Specific-use grain treatments								
Diatomaceous earth, amorphous silica (Dryacide®)[8]	Nil[2]	Effective control	Effective control	Effective control	Effective control	Not registered	Not registered	Effective control

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: GRDC

Fumigation with phosphine is a common component of many integrated pest control strategies (Photo 12).

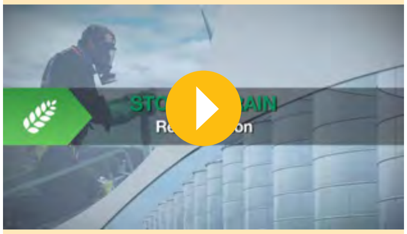
Taking fumigation shortcuts may kill enough adult insects in grain so it passes delivery standards, but the repercussions of such practices are detrimental to the grains industry.

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.]

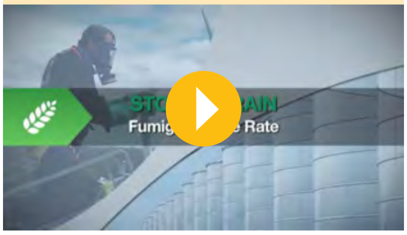


Photo 12: *Phosphine is widely accepted as having no residue issues.*

Photo: QDAFF

While phosphine has some resistance issues, it is widely accepted as having no residue issues for grain or pulses. The grain industry has adopted a voluntary strategy to manage the build-up of phosphine resistance in pevsts. 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. [23]

Phosphine application

For effective phosphine fumigation, a minimum of 300 parts per million (ppm) gas concentration for seven days or 200ppm for 10 days is required. Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3ppm 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.

23 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry, Cooperative Research Centre for National Plant Biosecurity, https://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 parts per million (ppm) for seven days (when grain is above 25°C) or 200ppm 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. [24]

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. [25]

13.4 Grain protectants for storage

Lesser grain borer's (*Rhyzopertha dominica)* widespread resistance to grain protectants is ending with the availability of deltamethrin (eg K-Obiol) and spinosad (eg 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

24 GRDC Stored Grain Information Hub. Grain Fumigation – A guide. http://storedgrain.com.au/fumigation-guide/

25 C Warrick (2012) Fumigating with phosphine, other fumigants and controlled atmospheres: Do It right—do it once. A Grains Industry Guide. January 2011. Reprinted June 2012, https://grdc.com.au/__data/assets/pdf_file/0025/206791/fumigating-with-phosphine.pdf.pdf

also ensure the product is used in the way that minimises the development of insect resistance and increase it usable life. [26]

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. [27]

13.5 Aeration during storage

13.5.1 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 litres per second per tonne.
- 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.
- 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.

26 GRDC Stored Grain information hub. K-Obiol Combi. http://storedgrain.com.au/k-obiol-combi/

27 GRDC Stored Grain information hub. Conserve On-farm. http://storedgrain.com.au/conserve-farm/

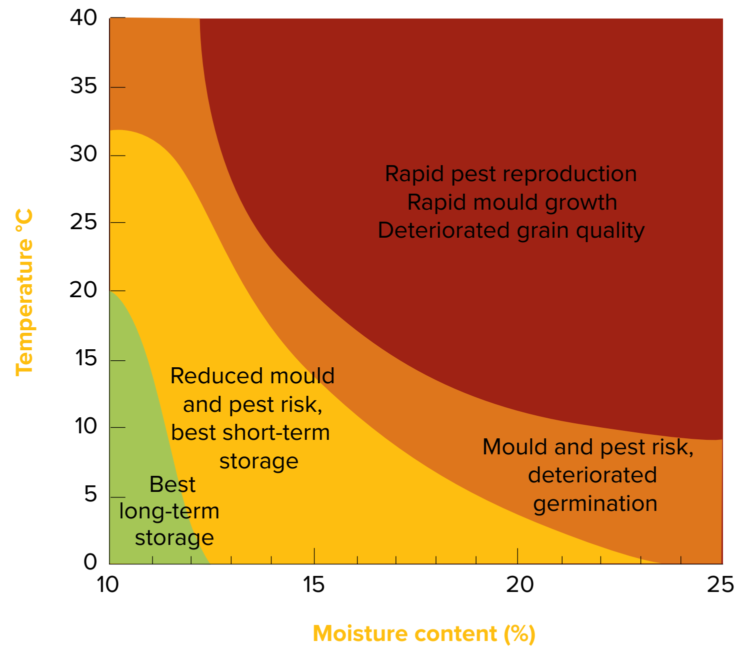


Figure 4: *Effects of Temperature and moisture on stored grain.*

Source: CSIRO Ecosystems Sciences in GRDC

13.5.2 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 litres per second per tonne. 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.

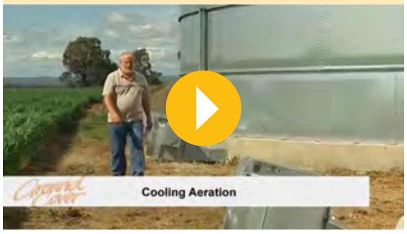
Blending

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 (Figure 5). [28]

28 GRDC Stored Grain Information Hub: Dealing with high moisture grain. http://storedgrain.com.au/dealing-with-high-moisture-grain/

VIDEOS

WATCH: Grain Storage Cooling Aeration.



MORE INFORMATION

GRDC Aerating Stored Grain – Industry Guide.

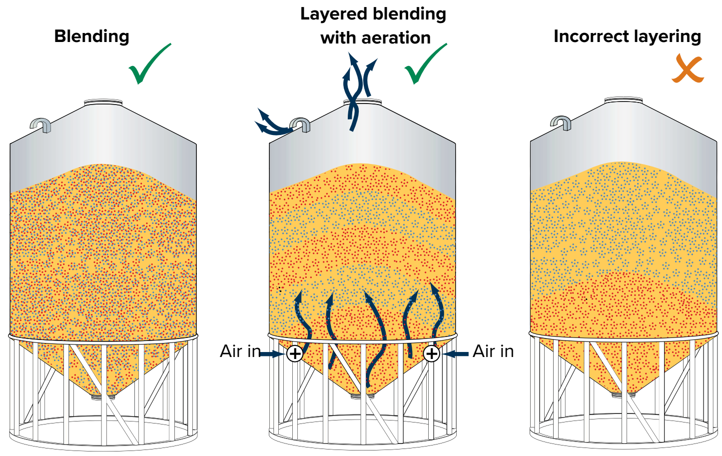


Figure 5: *Diagram demonstrating the correct practices for blending.*

Source: Kondinin Group in GRDC

Seed viability

Research trials reveal that cereal grain at 12% moisture content stored for six months at 30–35°C (unaerated grain temperature) will have reduced germination percentage and seedling vigour.

13.5.3 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.

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 13). 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 13: *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. For example, Table 4 shows that grain at 25°C and 14% moisture content has an equilibrium point of the air around it at 70% relative humidity. In order to dry this grain 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 4, 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 4: *Equilibrium moisture content for wheat.*

Relative humidity (%)	Temperature 15	Temperature 25	Temperature 35
	Grain moisture content %		
30	9.8	9.0	8.5
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

Note: values may be different for triticale grain.

Source: GRDC

VIDEOS

WATCH: Aeration drying – getting it right.

MORE INFORMATION

Dealing with high moisture grain.

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. [29]

13.5.4 Aeration controllers

Aeration controllers manage both aeration drying, cooling and maintenance functions in up to ten separate storages (Photo 14). The unit it takes into account the moisture content and temperature of grain at loading, 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 combine the ability to control all three functions, but automatically selects the correct type of aeration strategy to obtain the desired grain moisture and temperature. [30]

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 during November through to March.

Before replicating similar results on farm, growers need to:

- Know the capacity of their existing aeration system.
- Determine whether grain requires drying before cooling can be carried out.

29 GRDC Stored Grain Information Hub: Dealing with high moisture grain. http://storedgrain.com.au/dealing-with-high-moisture-grain/

30 GRDC. (2007). Ground Cover Issue 57 – New Generation in aeration controller. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-supplements/ground-cover-issue-57-grain-storage-supplement/new-generation-aeration-controller

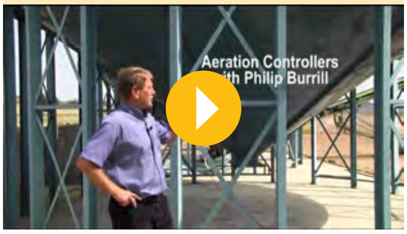
- Understand the effects of relative humidity and temperature when aerating stored grain.
- Determine the target conditions for the stored grain.

Photo 14: *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.



Environmental issues

Key messages

- Triticale appears to be more sensitive to frost damage than other cereals. Dry sowing for a portion of the crop is one option that has proven very successful, and can be considered for triticale as well as other cereals.
- Among the cereals, triticale has the best adaptation to waterlogged soils and those with high pH (alkaline soils).
- Triticale is also tolerant of low pH (acid) soils, grows well on sodic soils, and tolerates soils high in boron.
- Farmers appreciate the ability of triticale to tolerate periods of drought through the growing season, and at the other extreme, its tolerance of waterlogging.
- The crop is highly tolerant to soil with high concentrations of aluminium and to saline soils.

Being a derivative of rye, triticale has always been assumed to be relatively resistant to abiotic stress (i.e. non-living factors such as frost or drought that adversely affect the plant). Its high productivity is most likely derived from high rates of carbon assimilation linked to stomatal physiology and, probably, low respiration rate. Triticale retains good to excellent adaptation to conditions of limited water supply and problem soils with conditions such as salinity, low pH, mineral toxicity or deficiency, and waterlogging. [1]

MORE INFORMATION

The abiotic stress response and adaptation of triticale

Agronomist's guide to information for managing weather and climate risk

Frost – Frequently Asked Questions booklet

14.1 Frost issues for this crop

Key points:

- Frost events can have major and sudden impacts on cereal yields.
- Frost is a relatively rare occurrence but some areas are more prone to it.
- There has been an increase in frost frequency in many areas in the last 20 years.
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect the full extent of the damage done. [2]
- Triticale has been estimated to be one of the cereals most susceptible to frost. Crop susceptibility to frost from most to least susceptible is triticale, wheat, barley, cereal rye, and oats. [3]

Frost is a complex and erratic constraint to Western Australian cropping systems, and can result in dramatic losess to a grower's business. In recent decades, the frost patterns in WA have changed, so that now:

- WA's frost window has widened, and on average frosts start three weeks earlier and finish two weeks later in the year.
- Consecutive frost events have increased by an average of up to three days at a time, and mostly occur in August and September in the frost-prone regions.
- Minimum temperatures of frosts are getting colder.

Due to the nature of frost and its damaging effects, an integrated approach to managing it is recommended. This means making complex decisions that involve strategically combining information on environmental, management, and genetic approaches to cater to your situation. Risk assessment, property mapping, crop type, variety choice, sowing time, and stubble load are key pre-seeding factors that

1 A Blum (2014) The abiotic stress response and adaptation of triticale: a review. Cereal Research Communications, 42 (3), 359–375.

2 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

3 GRDC (2009) Managing the risk of frost. Factsheet. GRDC, https://grdc.com.au/resources-and-publications/all-publications/bookshop/2009/03/grdc-fs-frostrisk

growers can consider to reduce the risk of crop losses from spring frosts in high-risk areas. [4]

Frost occurs on clear nights in early spring when the air temperature drops to 2°C or less. Damage to crops from frost may occur at any stage of development, but is most damaging at and around flowering. Symptoms of frost damage can occur as sterility and stem damage. Physical damage to the plant occurs when ice forms inside the plant tissue, and, in the process of expanding, bursts tissue membranes, and causing mechanical damage and dehydration injury. Frost can reduce both grain yield and quality. [5]

Winter cereals are most susceptible to low temperatures during the reproductive stage as reproductive parts are not protected by the leaf sheaths and ice can nucleate directly on them. As a result, complete or serious yield losses are felt when frost occurs between the booting and grain ripening stages (Photo 1). [6] Identification of winter cereals with reproductive frost tolerance is a priority for frost research in Australia.

Photo 1: *Frosted cereal grain head.*

Source: GRDC

Once heads and grain have been frosted, small discoloured grain may be produced (Photo 2). [7] In addition to direct yield loss, frost also results in economic losses by

4 GRDC (2016) Pre-seeding planning to manage frost risk in WA. GRDC, https://grdc.com.au/Media-Centre/Hot-Topics/Preseeding-planning-to-manage-frost-risk-in-WA/Details

5 DAFWA (2016) Frost and cropping. DAFWA, https://www.agric.wa.gov.au/frost/frost-and-cropping

6 GRDC (2014) Frost publication addresses hot research topic. GRDC, https://grdc.com.au/news-and-media/news-and-media-releases/west/2014/03/frost-publication-addresses-hot-research-topic

7 S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

causing the crop quality to drop because it has lower organic matter digestibility and lower metabolisable energy. Frost can cause reductions in grain size, decrease flour extraction, decrease dough strength and baking quality, and cause increases in flour ash and α-amylase activity.

Photo 2: *Comparison of healthy (left) and frost-damaged (right) H20 triticale grain.*

Source: Tshewang 2011

14.1.1 Industry costs

Frost is a significant problem in the wheat growing regions of WA and a direct revenue loss of more than AU$ 100 million has been recorded in the state within one season. [8] When another major frost event hit WA growers in September 2016, it was estimated that yield losses of 1.5 million tonnes were expected. [9]

The real cost of frost is a combination of the actual cost due to reduced yield and quality, and the hidden cost of management tactics used to try and minimise the damage of predicted frosts. These latter costs include:

- Delayed sowing, which is associated with lower yields.
- Sowing less profitable crops such as barley and oats
- Avoiding cropping on the valley floors, where some of the most productive parts of the landscape are.

The historical incidence of frost varies strongly across the agricultural regions of Western Australia, with the greatest occurrence being in the central, eastern, and southern regions. Northern and coastal regions, in general, have a lower risk.

Frosts can also have a large social impact, as they occur so suddenly, unlike droughts, which develop more slowly, so growers can adapt to them mentally and financially by reducing inputs as they unfold.

8 GRDC (2009) GroundCover Issue 79: Early season planning to minimise frost. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-79-march-april-2009/early-season-planning-to-minimise-frost-risk

9 T de Landgrafft (2016) West Australian grain crop downgraded 18 per cent thanks to frost damage. 7 November. ABC News, http://www.abc.net.au/news/2016–11-07/wa-frost-giwa-report-downgrades-tonnage/8001558

14.1.2 Triticale and frost

Triticale has been rated as susceptible to frost damage (Photo 3). One study has ranked frost resistance in desecending order of rye, bread wheat, triticale, barley, oats, and durum wheat, and another study reported that triticale is the most susceptible crop, followed by wheat, barley, rye and oats. While species difference in frost tolerance do exist, frost damage is also determined by other factors such as crop growth stage and environmental conditions.

One of the reasons a greater area is not devoted to triticale on most farms is its poor tolerance to frost at flowering. While most cereals can suffer yield loss to frost at flowering, triticale is regarded as one of the most likely to do so. [10] Growers have reported that frost susceptibility was one of their main constraints in triticale production and expansion. [11]

Photo 3: *Frost-damaged grain head of H20 triticale plant (left), and cold damage to triticale leaf (right).*

Sources: left, S. Tshewang, right, Florida Downunder

IN FOCUS

Frost tolerance in triticale and other winter cereals at flowering

A series of experiments was conducted to evaluate the relative reproductive frost tolerance in different commercial triticale genotypes, and how they compared with two other winter cereals, wheat and barley. Eight triticales (cv. Bogongⓓ, Tahara, H20, H151, H418, H426, JRCT 74 and JRCT 400), four bread wheats (cv. Kite, Ventura, Young and Wyalkatchem), one durum wheat (cv. Bellaroi) and one barley (cv. Kaputar) were tested over two years (2009 and 2010). In addition, the roles of cold hardening and potassium fertilisation in frost tolerance were also investigated using the triticale variety H426. The plants were grown in a glasshouse and treated to a single overnight natural frost at flowering (±5 days). The damage was assessed by counting the number of fertile grains at maturity.

The collated results of two years showed a difference in frost tolerance between the different triticale varieties. However, the difference was not huge and varietal responses were mainly determined by frost temperature.

10 J Lawes, R Jessop, C Bluett, M Jenkinson (1998) Frost tolerance of triticale varieties 1998. Online Farm Trials, http://www.farmtrials.com.au/trial/15345

11 J Roake, R Trethowan, R Jessop, M Fittler (2009) Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Temperatures particularly below –3.9°C were found to be destructive (Figure 1). At –4.2°C, there was little effect on barley floret survival, while triticale and wheat were severely affected (Figure 2). [12]

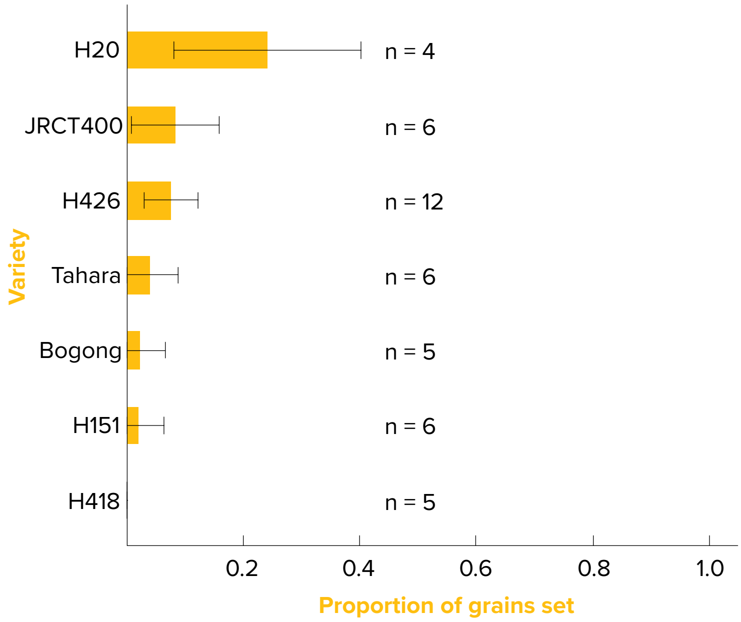


Figure 1: *Proportion of grains that set in different triticale varieties at –4.2°C (2009). Bars are the lower and upper 95% confidence interval. N = the number of heads frosted.*

Source: S Tshewang 2011

12 S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

VIDEOS

WATCH: Plant frost mechanisms with Glenn McDonald

MORE INFORMATION

Frost and plant physiology: Q&A with Glenn McDonald

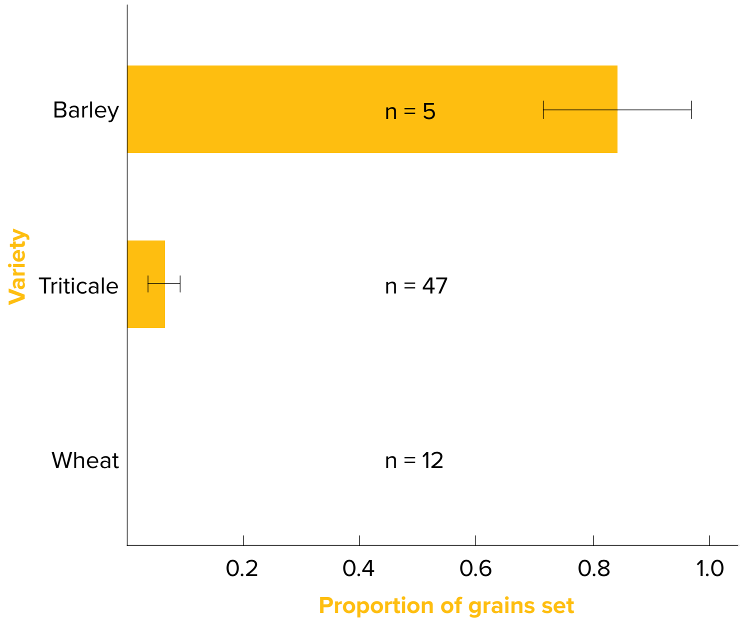


Figure 2: *Proportion of grains that set in different species at –4.2°C (2009). Bars are the lower and upper 95% confidence interval. n = number of heads frosted.*

Source: S Tshewang 2011

14.1.3 Conditions leading to frost

Clear, calm and dry nights following cold days are the precursor conditions for a 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 and settled, cloudless weather (Figure 3). [13] When the loss of heat from the earth during the night decreases the temperature at ground level to zero, a frost 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 gets to zero, how long its stays below zero, and the how far below zero it falls.

13 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

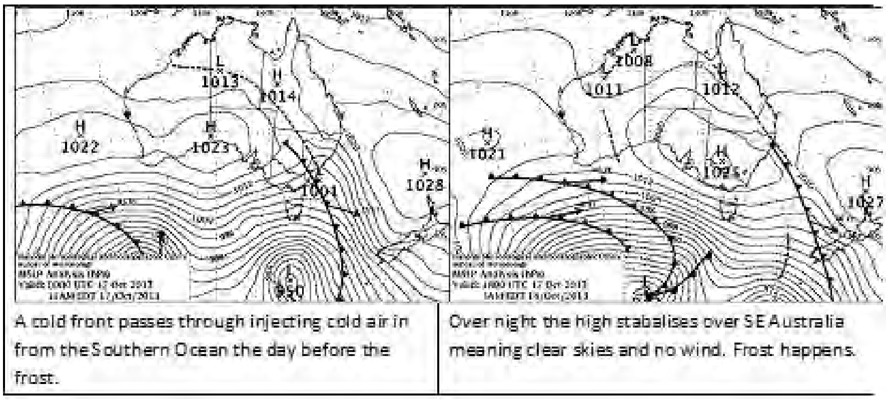


Figure 3: *A cold front passes through, injecting cold air in from the Southern Ocean the day before frost (left). Overnight the high-pressure system stabilises over south-eastern Australia, which means clear skies and no wind leading to a frost event (right).*

Source: GRDC.

Though temperatures (particularly in winter and spring) are getting warmer, frost is still a major issue, and likely to remain so. CSIRO researchers found that in some areas of Australia the number of frost events is increasing (with the greatest increase in August), and that central western NSW, the Eyre Peninsula, Esperance and the northern Victorian Mallee were the only major crop growing areas to be less affected by frost from 1961 to 2010 (Figure 4). [14] This increase is thought to be caused by the latitude of the subtropical ridge of high pressure drifting south (causing more stable pressure systems) and the existence of more El Niño conditions during this period. [15]

VIDEOS

WATCH: GCTV20: Frost's emotional impact—is it greater than its economic impact?.

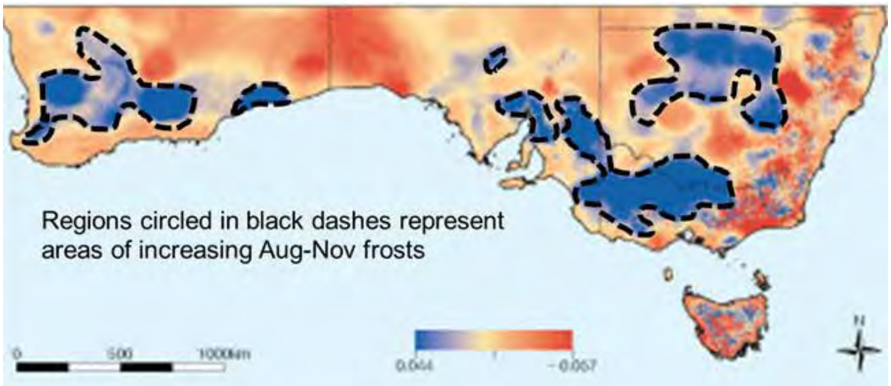


Figure 4: *Region of increasing August–November frost events.*

Source: GRDC

14.1.4 Diagnosing stem and head frost damage in cereals

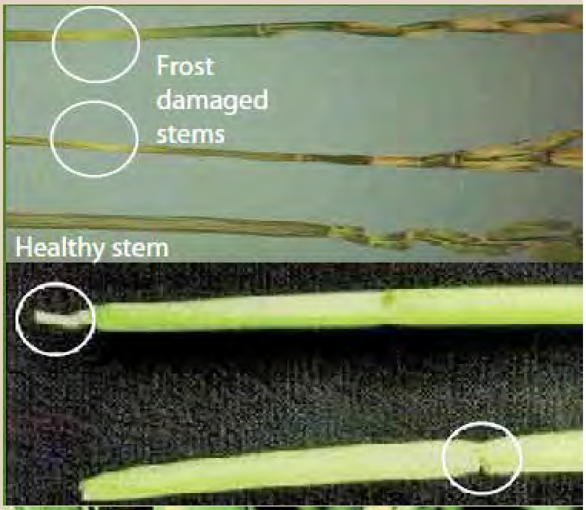
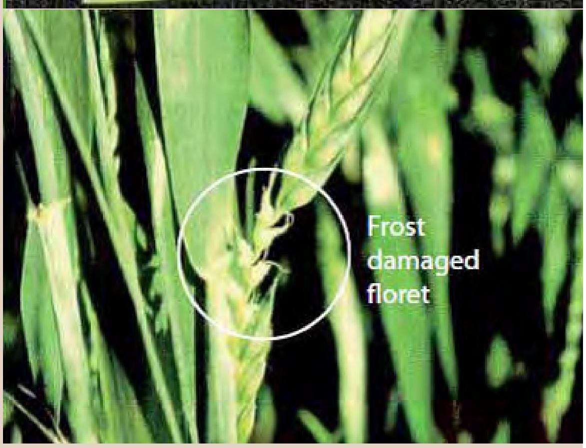
Table 1 shows how to diagnose frost damage to stems and heads. Although the information given is for wheat, it applies equally to triticale. [16]

14 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

15 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

16 R Barr (2014) Frost-damage concern for south-eastern Australia. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2014/09/Frost-damage-concern-for-southeastern-Australia

Table 1: *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	
Elongation (before and after head emergence)	Pull back leaf sheath or split stem to inspect damage	Stem has a pale green to white ring that usually appears sunken, rough to touch, and soft to squeeze 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 has emerged it is likely that the flowering parts or developing grain has sustained damage If the head is in the boot then ongoing monitoring is required to assess the level of damage	

Crop growth stage	Inspection details	Frost symptoms in wheat	Example
Flowering and post-flowering (Flowering is the most vulnerable stage, because exposed florets cannot tolerate low temperatures and are sterilised)	Peel back the lemma (husk), inspect the condition of the florets (floral organs) in the head	Grain will not form in frosted florets Some surviving florets may not be affected Pollen sacs (or anthers, normally bright yellow) but become dry, banana-shaped and turn pale yellow or white	

Source: GRDC

What to look for in the paddock

- Symptoms may not be obvious until 5–7 days after the frost.
- Heads on affected areas have a dull appearance that becomes paler as frosted tissue dies (Photo 4). [17]
- At crop maturity, severely frosted areas remain green longer.
- Severely frosted crops have a dirty appearance at harvest, due to blackened heads and stems, and discoloured leaves.

Photo 4: *Frost damage in wheat at Black Rock in the South Australian upper north.*

Photo Jim Kuerschner

What to look for in the plant

- Before flowering:

17 R Barr (2014) Frost-damage concern for south-eastern Australia. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2014/09/Frost-damage-concern-for-southeastern-Australia

- Freezing of the emerging head by cold air or water is caught next to the flag leaf or travels down the awns into the boot. Individual florets or the whole head can be bleached and shrivelled, stopping grain formation. Surviving florets will form normally.
- Stem frost by a small amount of water that has settled in the boot and frozen around the peduncle. Symptoms include paleness or discolouration, 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. In normal flowers the ovary is bright white and 'crisp' when squeezed. As the grain develops, it turns green in colour.
- Anthers are dull-coloured and are often banana-shaped. Normal anthers are green to yellow before flowering, and 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 or dough. Healthy grain is light to dark green and plump, and exudes white milk or dough when squeezed (Photo 5).
- Frosted grain at the dough stage is shrivelled and creased along the long axis, rather as though a pair of pliers has crimped the grain (Photo 6). [18]

Photo 5: *A normal cereal head (left) compared to frost-damaged cereal showing discoloured glumes and awns.*

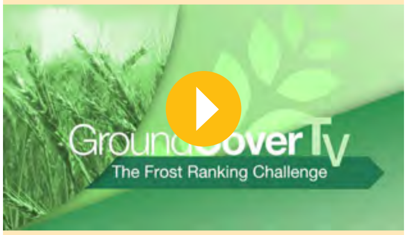
Source: DAFWA

18 DAFWA (2015) Diagnosing stem and head frost damage in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-stem-and-head-frost-damage-cereals

VIDEOS

WATCH: GCTV15: Frost ratings

WATCH: GCTV15: The frost ranking challenge



WATCH: GCTV12: Frost susceptibility ranked

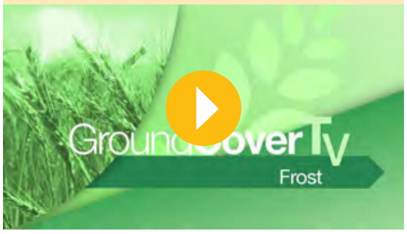


Photo 6: *Frosted hollow grain dries back to a typically shrivelled appearance.*

Source: GRDC

14.1.5 Managing frost risk

Key points:

- The widening of the frost 'season' has been exacerbated by changes in grower practices.
- Since 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.
- The occurrence of frost and damage to grain crops is determined by a combination of factors including temperature, humidity, wind, topography, crop species and variety, how the crop is managed, and soil type, texture, and colour.
- The 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.
- Methods to deal with the financial and personal impact of frost also need to be considered in the farm management plan.
- Careful planning and zoning, and choosing the right crops, are the best options to reduce frost risk. [19]

Significant frost damage has occurred several times in triticale crops in Australia in recent years. Triticale often suffers more from frost damage than wheat, hence it should generally be sown later. The risk of being frosted, particularly in low-lying paddocks, can be reduced by not planting too early; however, heat stress during grainfill may become a more important factor as the sowing date is delayed. Newer varieties with some winter habit, combined with the ability to cope with drier seasons, offer growers a significant improvement in variety choice. [20]

The variability in the incidence and severity of frost means that growers need to adopt a number of strategies as part of their farm management plan. These include pre-season, in-season, and post-frost strategies. There are two types of pre-season management tactics available for growers:

1. at the level of farm management planning; and
2. within identified frost zones of a farm.

19 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

20 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

Farm-management planning tactics

Step 1: Assess personal approach to risk

Consider your personal approach to risk in your business; every individual will have a different approach. As part of this process, identify and measure the extent of the risk, evaluate risk-management alternatives and tailor the risk advice according to your attitude to and level of comfort with risk. The risk of frost can promote conservative farming practices, which should be carefully and regularly reviewed in light of the latest research.

Step 2: Assess frost risk of property

Carefully consider the risk of your property incurring frosts due to the location. Use historical seasonal records and forecasts. Because cold air will flow into lower areas, spatial variability (topography and soil type) across the landscape should also be considered. Temperature-monitoring equipment, such as Tinytags, iButtons and weather stations, can determine temperature variability across the landscape.

Step 3: Diversify the business

A range of enterprise options should be considered as part of a farm-management plan, so as to spread financial risk in the event of frost damage. Options are subject to the location of the business and skill set of the manager, but the largest financial losses with frost have occurred where growers have a limited range of enterprises or crop types. Intensive-cropping systems, especially those focused on canola and spring wheat, are more at the mercy of frost than a diversified business, as both crops are highly susceptible to frost.

Step 4: Zone property and paddock

Paddocks or areas in paddocks that are prone to frost can be identified through experience, and the use of precision tools such as topographic, electromagnetic, and yield maps, and temperature monitors to locate susceptible zones. This can help determine the appropriate management practice to use to mitigate the incidence of frost. Be aware that frost-prone paddocks can be high-yielding areas on a farm when frosts do not occur.

Frost-zone management tactics

Step 1: Consider enterprise within a zone

The use of identified frost zones should be carefully considered, for example using them for grazing, hay or oat production, and avoiding large-scale exposure to frost of highly susceptible crops like peas or expensive crops like canola. It may be prudent to sow annual or perennial pastures on areas that frost regularly, in order to avoid the high costs of crop production.

Step 2: Review nutrient management

For high-risk paddocks, set fertiliser (nitrogen, phosphorus, potassium) and seeding rates to achieve realistic yield targets, rather than for extra high yields. By doing this, the grower should minimise their financial exposure, reduce frost damage and increase whole-paddock profitability over time. Nutrients not applied in these paddocks could be reallocated to lower-risk areas of the farm.

While high levels of nitrogen (N) increase yield potential, N also promotes the production of vegetative biomass and increases the susceptibility of the crop to frost. Using conservative N rates at seeding and avoiding late top-ups results in less crop damage.

It is best if crops are not deficient in potassium or copper, as insufficient amounts of these elements may increase susceptibility to frost events. The levels of these nutrients can be assessed from initial soil tests and with plant-tissue testing. Copper deficiency can be ameliorated with a foliar spray pre-flowering and as late as the booting stage to optimise yield, even in the absence of frost. Potassium plays a role

VIDEOS

WATCH: Frost Initiative: Do micronutrients reduce frost risk?

WATCH: MPCN: Copper and frost relationship investigated

in maintaining cell-water content in plants, and it has been shown that plants deficient in potassium are more susceptible to frost. Soils that are deficient in potassium could benefit from increasing potassium levels at the start of the growing season. However, it is unlikely that there will be a benefit of extra potassium applied to plants that are not potassium-deficient.

There is no evidence that applying other micronutrients has any impact to reduce frost damage.

Step 3: Modify the soil heat-bank

The soil heat-bank helps reduce the risk of frost (Figure 5). [21] Farmers can manipulate the way heat-banks operate, to store heat absorbed during the day and release it during the night into the crop canopy, to reduce the impact of a frost.

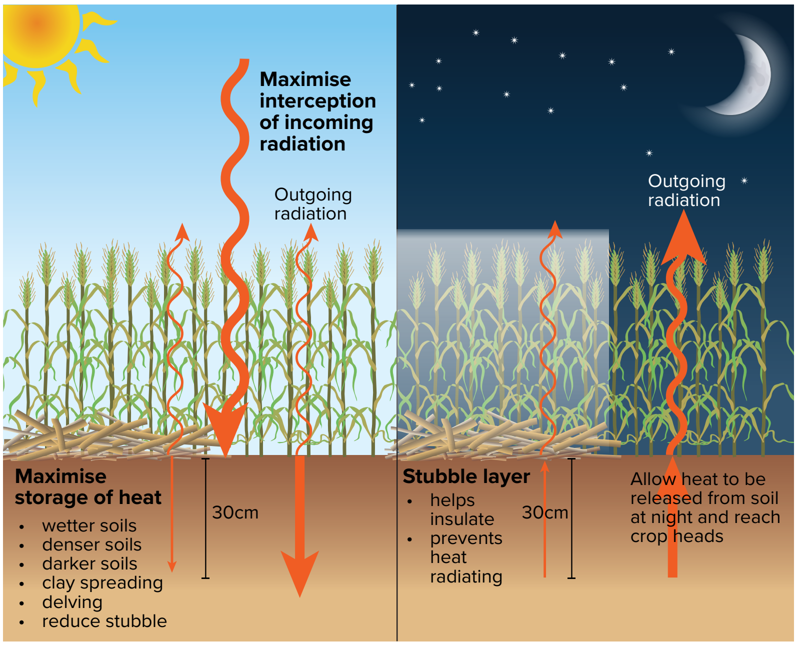


Figure 5: *The soil heat-bank captures heat during the day and radiates that heat into the crop canopy overnight, which warms flowering heads and minimises frost damage.*

Source: GRDC

Agronomic practices that may assist with storing heat in the soil heat-bank include:

- Practices that alleviate non-wetting sands, such as clay delving, mouldboard ploughing or spading, have multiple effects, and include increasing heat storage, nutrient availability and infiltration rate.
- Rolling sandy soil and loamy clay soil after seeding can reduce frost damage. It also prepares the surface for hay cutting should that be necessary.
- Reducing the amount of stubble—stubble loads above 1.5 t/ha in low-production environments (2–3 t/ha) and 3 t/ha in high-production environments (3–5 t/ha) generally increase the severity and duration of frost events, and have had a detrimental effect on yield under frost.
- Halving the normal seeding rates can reduce frost severity and damage by creating a thinner canopy and more tillers, which result in a spread of flowering time. However, weed competitiveness can be an issue.

21 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

- Cross-sowing—crops sown twice, with half the seed sown in one direction and half in the other, have a more even plant density. This means that heat is released from the soil heat-bank more slowly, to warm the crop canopy at head height in the early morning when frosts are more severe. This practice, however, increases sowing costs.

IN FOCUS

Stubble reduces frost severity

In a 2012 trial at Wickepin, WA, yields of wheat were 0.7 tonnes per hectare higher in burnt stubble high in the landscape (where there was moderate frost risk) and 0.3 t/ha higher in burnt stubble lower in the landscape where the frost risk is higher (Table 2). Wheat in the high stubble plots had almost 85% sterility, while plants beyond the stubble had 20–30% sterility, indicating that the high stubble load increased the frost damage. Temperature data showed substantially colder temperatures in plots with high stubble. This is because stubble can insulate the soil surface, which lowers the amount of heat absorbed into the soil compared with paddocks without stubble. Less heat is radiated from the soil in stubble paddocks at night, which lowers the canopy temperature and leads to greater frost severity, duration and damage. [22] Reducing the amount of stubble is likely to reduce the risk of frost damage in triticale.

Table 2: *Yield and yield component data for Nyabing. Where frost induced sterility (FIS), harvest index (HI) 100 grain weight (100GW) and screenings.*

Position	Low landscape			High landscape		
Stubble	**Additional***	**Standing**	**Removed**	**Standing**	**Removed**	**LSD0.05**
Stubble biomass in August	3.5	2.6	0.5	2.6	0.5	0.5
Average minimum canopy temperature during September–October frosts	–2.4	–2.0	–1.8	–1.1	–1.3	0.16
Hours below zero	45	33	32	22	24	
Yield (t/ha)	0.6	1.0	1.8	1.9**	2.5**	0.40
FIS (%)	87	33	35	20	13	4.0
Screenings (%) <2mm	56	9	9	13	13	5.5

*Additional stubble plot was unreplicated and was only located low in the landscape.
**Yield estimated from small plot trial harvester cuts with two replicates per plot.
Source: GRDC.

Step 4: Select appropriate crops

Crop selection is an important factor to consider for frost-prone paddocks. Crops grown for hay are harvested for biomass, so the problem of grain loss from frost does not arise. Pasture rotations are a lower-risk enterprise, and oats are the most frost-tolerant crop during the reproductive stage. Barley is more tolerant than wheat at flowering, but it is not known if barley and wheat have different frost tolerance during

22 B Biddulph in J Paterson (2014) Groundcover Supplement Issue 109: Frost - Stubble lifts frost severity. https://grdc.com.au/__data/assets/pdf_file/0028/75835/gcs109highres-pdf.pdf.pdf

MORE INFORMATION

Yield Prophet®

Flower Power

grainfill. Canola is an expensive crop to risk on frost-prone paddocks, due to high input costs.

Yield Prophet® and Flower Power are useful tools to match the flowering time of varieties to your own farm conditions.

Step 5: Manipulate flowering times

When cereals are sown in frost-risk areas, a good tactic is to ensure the flowering window of the cropping program is spread widely. This can be done by using more than one variety and manipulating sowing date and planting varieties with different phenology drivers so that crops flower over a wide period during the season. It should be noted that flowering later than the frost may result in lower yields in seasons with hot, dry finishes, as plants will be subjected to heat and moisture stress.

Staging sowing dates over a 3–6-week period is recommended. If sowing just one variety, this would provide a wide flowering window. If sowing more than one variety: sow winter wheat first; then a long-season spring wheat or a day-length-sensitive wheat; then an early-maturing wheat last. A whole-wheat program like this is planned so that flowering occurs over a two-week period, potentially exposing it to more frost risk but maximising the yield potential in the absence of frost. Even with this strategy in place, it is possible to have more than one frost event that causes damage. Flowering over a wide window will probably mean that some crop will be frosted, but the aim is to reduce extensive loss rather than prevent it altogether.

Sowing at the start of a variety's preferred window will achieve higher yields at the same cost as sowing late. Sowing time remains a major driver of yield in all crops, so the primary objective with this tactic is to achieve a balance between crops flowering after the risk of frost has passed and before the onset of heat stress. The loss of yield from sowing late to avoid frost risk is often outweighed by the gains from sowing on time to reduce heat and moisture stress in spring.

To minimise frost risk, there needs to be a mix of sowing dates, crop types, and maturity types to be able to incorporate frost-avoidance strategies into the cropping system. In years of severe frost, regardless of which strategy is adopted it may be difficult to prevent damage.

Trials have shown that blending a short-season variety with a long-season variety is an effective strategy. However, the same effect can be achieved by sowing one paddock with one variety and the other with another variety to spread risks. [23]

In regions where spring frosts are a likely problem, a delay of 7–10 days in sowing compared with main-season wheat varieties should reduce potential frost effects. The avoidance of frost-prone areas (e.g. low-lying paddocks and creeks) will also reduce possible frosting effects. [24]

In monetary values, the loss by delayed sowing in WA alone can reach about $18.4 million (Table 3). [25]

23 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

24 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

25 Hayman et al. (2007) in S Tshewang (2011) Frost tolerance in triticale and other winter cereals at flowering. Master's thesis. University of New England, https://e-publications.une.edu.au/vital/access/manager/Repository/une:8821;jsessionid=C91FFA8964B3A49AD3A44FC3BD03EA2E?exact=sm_contributor%3A%22Birchall+C%22

MORE INFORMATION

[Effect of fodder cuts on grain yield of early sown wheat and triticale 2006]

Table 3: *Estimated cost of delayed sowing of wheat to minimize the impact of frost.*

Site	Days delayed	Loss (kg/ha)	Loss ($/ha)	Average loss ($/ha)
Merredin	18	360	79	16
Narrogin	10	200	44	14

data from Hayman et al. 2007

Step 6: Fine-tune cultivar selection

As no wheat or barley varieties are tolerant to frost, consider using varieties that have lower susceptibility to frost during flowering, as a means of managing the frost risk of the cropping program while maximising yield potential. There is no point selecting less-susceptible varieties for the whole cropping program if there is an opportunity cost of lower yield without frost.

Preliminary ranking information for current wheat and barley varieties for susceptibility to reproductive frost is available from the National Variety Trials website. A new variety should be managed based on how known varieties of similar ranking are managed. [26]

Guidelines to 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 grainfilling in the short window of opportunity after the main frost risk has passed and before day-time 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 gives a much higher 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

Temperatures taken in the crop are useful in determining whether the 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 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, either. In crops, the temperature can vary several degrees from the temperature measured in the screen. On nights of still, cold air, clear skies, and low humidity, temperatures can drop rapidly, resulting in radiant frost (Figure 6). [27] Temperatures in a crop can vary widely, due to differences in topography, micro-environments and recording methods.

26 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

27 J Christopher, B Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) An analysis of frost impact guidelines to reduce frost risk and assess frost damage. GRDC Update Paper. GRDC, 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

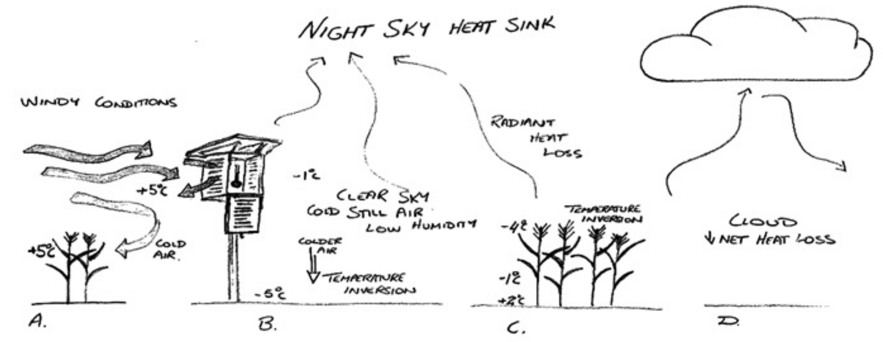


Figure 6: *If clear skies and still, cold, dry air coincide, heat can be lost rapidly to the night sky, resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than reported screen temperatures. Some indicative temperatures are illustrated for (A) windy conditions, (B) clear, still conditions in an open area, (C) clear, still conditions in a cropping area, and (D) cloudy conditions.*

Source: GRDC

Measurements taken using exposed thermometers at canopy height (Photo 7) give a much more accurate indication of the likelihood of crop damage. [28]

Photo 7: *Canopy temperature being measured using a calibrated minimum–maximum thermometer. For best results, a minimum of two or three field thermometers are required 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)

28 J Christopher, B Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) An analysis of frost impact guidelines to reduce frost risk and assess frost damage. GRDC Update Paper. GRDC, 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

14.1.6 What to do with a frosted crop

Once a frost has occurred, especially at or after flowering, the first step is to inspect the crop and collect a random sample of heads to estimate the yield loss incurred. In the event of severe frost (Photo 8), [29] monitoring needs to occur for up to two weeks after the event to detect all the damage.

Photo 8: *Crops in severely frosted areas such as this mature later and are often stained or discoloured.*

Source: DAFWA

After the level of frost damage has been estimated, the next step is to consider options for the frost-damaged crop. The grower must weigh up the advantages and disadvantages of each option (Table 4). [30] A few of these options are discussed below.

29 DAFWA (2015) Diagnosing head and stem frost damage in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-stem-and-head-frost-damage-cereals

30 GRDC (2014) Frost damage concern for south-eastern Australia. GRDC, https://grdc.com.au/news-and-media/news-and-media-releases/south/2014/09/frost-damage-concern-for-southeastern-australia

Table 4: *Management options for frost damaged crop, each with advantages and disadvantages.*

Options	Advantages	Disadvantages
Harvest	Salvage remaining grain More time for stubble to break down before sowing Machinery available	Cost 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 to rake Time taken
Graze	Feed value	Insufficient 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	With a thick crop, difficulty getting chemicals onto all of the weeds May not be as effective as burning Boom height limitation Costs $5/ha, plus the cost of herbicide Some grain still in crop
Plough	Recycles nutrients and retains organic matter Stops weed seed set Green manure effect	Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swath	Stops weed seedset 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 Costs $20/ha to swathe Costs $5/ha per herbicide to spray
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 Loss of organic matter

Source: GRDC

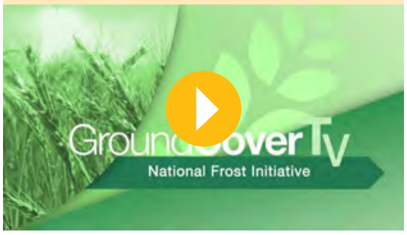
Option 1: Take through to harvest

If the frost is prior to or around growth stage GS 31 to GS 32, most cereals can produce new tillers to compensate for damage, provided spring rainfall is adequate, so it may be worth keeping the crop and harvesting it. Tillers already formed but lower in the canopy may become important. Naturally, tiller response depends on the location and severity of the damage. Compensatory tillers will mature later, but where

VIDEOS

WATCH: GCTV3: Frost R&D

WATCH: GCTV16: National Frost Initiative



MORE INFORMATION

Managing frost risk: Case studies of growers in Western Australia

GRDC factsheet, Managing frost risk

DAFWA, Frost risk: manage wheat variety and sowing time

soil-moisture reserves are high, or it is early in the season, they may contribute to grain yield.

A later frost is more concerning, especially for crops such as triticale, wheat and barley, as there is less time for compensatory growth. The grain yield needed to recover the costs of harvesting should be determined using gross margins.

Option 2: Cut and bale

Cutting and baling is an option when late frosts occur during flowering and through grainfill. Assess crops for hay quality within a few days of a frost and be prepared to cut a larger area than you had intended to before the start of the season.

Producing hay can also be a good management strategy to reduce stubble, the weed seedbank, and disease loads for the coming season. This may allow more rotational options in the following season to aid financial recovery from frost, for example to go back to cereal on cereal in paddocks cut early for hay. However, as hay making can be an expensive exercise, growers should have a clear path to market or a use for the hay on the farm before committing to this option.

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 into this option, especially if the paddock will be sown to crop the next year. Ploughing in the green crop is an option to return organic matter and nutrients to the soil, manage crop residues and weeds, and improve soil fertility and structure. The economics need to be considered carefully. [31]

Depending on the degree of damage incurred, the grain may still be very valuable as stock feed. Severely frosted grain may have a metabolisable energy (ME) of approximately 1MJ/kg lower than unfrosted grain. Provided allowance is made for this decrease in energy value, the grain is still valuable in a feed ration. [32]

Useful tools

- AgExcellence Alliance has an annotated list of several weather and farming apps.
- Plant-development apps, e.g. MyCrop, DAFWA's Flower Power
- Temperature monitors
- Yield Prophet®

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. It funds multidisciplinary projects in the following areas:

- Genetics—developing more frost-tolerant wheat and barley germplasm, and ranking current wheat and barley varieties for susceptibility to frost.
- Management—developing best-practice crop canopy, stubble, nutrition, and agronomic management strategies to minimise the effects of frost, and searching for innovative products that may minimise the impact of frost.
- Environment—predicting the occurrence, severity, and impact of frost events on crop yields and at the farm scale to enable better risk management. [33]

31 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

32 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

33 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

14.2 Waterlogging and flooding issues for triticale

Key points:

- Waterlogging occurs when roots cannot respire due to excess water in the soil profile.
- Though cereals can be more prone to waterlogging than other crop types, triticale has been found to be more tolerant of waterlogged conditions than wheat. [34]
- 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 time that crop roots are subjected to anaerobic conditions.
- While raised beds are an expensive management strategy, they are also the most effective at improving drainage.
- Waterlogging increases the release from soils of nitrous oxide (N2O), a particularly damaging greenhouse gas.

Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore spaces for plant roots to be able to respire adequately (Photo 9). [35] 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, so there is no universal level of soil oxygen that can be used to identify what constitutes waterlogged conditions. In addition, a plant's demand for oxygen in the root zone will vary with its stage of growth. [36]

Photo 9: *Waterlogged cereal paddock near Kendenup, WA.*

Source: DAFWA

Many wetland plants are specially adapted to cope with life in waterlogged soils: they have a combination of a high volume of aerenchyma (soft plant tissue containing air spaces) and a barrier to prevent radial oxygen loss (ROL) from roots. The lack of a barrier to ROL in dryland cereals presumably contributes to their sensitivity to soil waterlogging. [37]

Among the cereals, triticale has been reported to be more tolerant of waterlogged conditions than wheat. [38] Some farmers have noted that triticale also outperforms barley in areas prone to waterlogging. [39] At one farm, the variety Rufus was

34 CJ Thomson, TD Colmer, ELJ Watkin, H Greenway (1992) Tolerance of wheat (Triticum aestivum cvs Gamenya and Kite) and triticale (Triticosecale cv. Muir) to waterlogging. New Phytologist, 120 (3), 335–344.

35 DAFWA (2015) Management to reduce impact of waterlogging in crops. DAFWA, https://www.agric.wa.gov.au/waterlogging/management-reduce-impact-waterlogging-crops

36 D Bakker (2017) Waterlogging. Factsheet. Soilquality.org, http://soilquality.org.au/factsheets/waterlogging

37 AI Malik, AKMR Islam, TD Colmer. Physiology of waterlogging tolerance in wheat, hordeum marinum and their amphiploid

38 CJ Thomson, TD Colmer, ELJ Watkin, H Greenway (1992) Tolerance of wheat (Triticum aestivum cvs Gamenya and Kite) and triticale (Triticosecale cv. Muir) to waterlogging. New Phytologist, 120(3), 335–344.

39 GRDC (2006) Triticale. Ground Cover. No. 59. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-59/Triticale

completely under water for 4–5 days and still yielded 1.34 t/ha. It also carried no rust, and the straw was baled for sale to dairy producers. [40]

Researchers in WA explored the responses of two genotypes of wheat (Triticum aestivum cvs Gamenya and Kite) and one genotype of triticale (Triticosecale cv. Muir) in stagnant solution culture and in waterlogged soil, using plants that were 23 to 36 days old. The stagnant nutrient solutions decreased shoot fresh weight of Gamenya by 21% compared with aerated plants, while the shoot fresh weight of Muir was unaffected. Reductions in nodal root fresh weight under stagnant conditions were also less for Muir than Gamenya. [41]

Australian researchers have found that seed size is related to waterlogging tolerance. On average, larger seed results in greater plant growth for triticale cultivars, and seed mass is positively related to the plant biomass and adventitious nodal root mass under waterlogged conditions. [42]

14.2.1 Where does waterlogging occur?

Waterlogging occurs:

- Where water accumulates or drains poorly in areas such as valleys, at the change of slope, or below rocks.
- In duplex soils, particularly sandy duplexes with less than 30 cm of sand over clay.
- With deeper sown crops.
- In crops with a low nitrogen status.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [43]

Waterlogging greatly increases crop damage from salinity. Germination and early growth can be much worse in marginally saline areas after they have been waterlogged.

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 10). [44] 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. [45]

40 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

41 CJ Thomson, TD Colmer, ELJ Watkin, H Greenway (1992) Tolerance of wheat (Triticum aestivum cvs Gamenya and Kite) and triticale (Triticosecale cv. Muir) to waterlogging. New Phytologist, 120 (3), 335–344.

42 DK Singh, V Singh (2003) Seed size and adventitious (nodal) roots as factors influencing the tolerance of wheat to waterlogging. Crop and Pasture Science, 54 (10), 969–977.

43 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

44 B Cotching, D Bakker (2017) Waterlogging, Tasmania. Factsheet. Soilquality.org, http://soilquality.org.au/factsheets/waterlogging-tas

45 D Bakker (2017) Waterlogging. Factsheet. Soilquality.org, http://soilquality.org.au/factsheets/waterlogging

Photo 10: *Water fills a hole while digging in waterlogged soil.*

Source: Soilquality.org

14.2.2 Symptoms and causes

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. The lack of oxygen in the root zone of plants causes their root tissues to decompose. Usually this occurs from the tips of roots, and causes the 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 (e.g days to weeks), the plant will eventually die.

Most often, however, waterlogging does not last this long. 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 may not recover, 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.

What to look for in the paddock

- Poor germination or pale plants in areas where water collects, particularly on shallow duplex soils (Photo 11). [46]
- Wet soil and/or water-loving weeds are present.
- Early plant senescence in waterlogging-prone areas.

46 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

Photo 11: *Pale plants in waterlogged area.*

Source: DAFWA

What to look for in the plant

- Waterlogged seed will be swollen and may have burst.
- Seedlings may die before emergence, or be pale and weak if they do emerge.
- 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 12).
- Seminal roots may be damaged. As these roots are important for accessing deep subsoil moisture, waterlogging damage may leave the plants more sensitive to spring drought.

Plants are particularly vulnerable from seeding to tillering, with seminal roots being more affected than later forming nodal roots.

Photo 12: *Waterlogged roots, particularly seminal roots and tips, become brown and then die.*

Source: DAFWA

14.2.3 How waterlogging can be monitored

Waterlogging can be monitored by:

- Regularly checking water levels using bores or observation pits (but keep in mind that water tables can vary greatly over short distances).
- Observe plants for symptoms, and the paddock for clues, and verify by digging a hole in the paddock and watching for the appearance of water in it—plants can become waterlogged if there is a water table within 30 cm of the surface. There may be no indication of waterlogging at the surface. [47]

14.2.4 Other impacts of waterlogging and flood events

Heat from stagnant water

Stagnant water, particularly if it is 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, particularly leafy crops, exposed to off-farm run-off.

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 rain and sunny weather.

47 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

VIDEOS

WATCH: GCTV3: Big wet—managing strategies after flooding

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

Soils with a high clay content can become compacted and form a surface crust after heavy rainfall or flooding. Floodwater may also deposit a fine clay layer on top of the soil, and this will prevent oxygen penetrating 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 then, too. 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. [48]

14.2.5 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.
- Raised beds are more effective on relatively flat areas and on heavier-textured soils, but areas need to be large enough to justify the machinery costs. [49]

Drainage

Drainage is usually the best way of reducing waterlogging. 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.

Drain waterlogged soils as quickly as possible, and cultivate between rows to aerate the soil.

Other management options to reduce the impact of waterlogging include the choice of crop, seeding, and fertiliser, and weed control.

Drainage problems after flooding

After significant rain or flooding, inspect the crops as soon as 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 the 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 paddock
- improving surface drainage

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48 Queensland Government (2016) Managing risks to waterlogged crops. Queensland Government, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/managing-risks-waterlogged-crops

49 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

- installing subsurface drainage

If the drainage can't be improved, consider using the area for some other purpose (e.g. as a silt trap). [50]

Choice of crop species

Some species of grains crop are more tolerant of waterlogging than others. 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 first those paddocks that are susceptible to waterlogging. However, if waterlogging delays emergence and reduces cereal plant density to fewer than 50 plants/m2, 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 will take advantage of stressed crops.

Nitrogen fertiliser

Crops tolerate waterlogging better if the soils has a good nitrogen status before waterlogging occurs. Applying nitrogen at the end of a waterlogged period can be an advantage if nitrogen was applied at or shortly after seeding, because it avoids loss by leaching or denitrification. However, nitrogen cannot usually be applied from vehicles when soils are wet, so consider aerial applications.

If waterlogging is moderate (7–30 days), then nitrogen application after waterlogging events when the crop is actively growing is recommended where basal nitrogen applications were 0–50 kg N/ha. However, if waterlogging is severe (greater than 30 days), the benefits of nitrogen application after waterlogging are questionable. But this recommendation requires verification in the paddock at a range of basal nitrogen applications using a selection of varieties.

MORE INFORMATION

Should waterlogged crop be top-dressed with N fertiliser?

Weeds

Weed density affects a crop's ability to recover from waterlogging. After the water has drained, they will compete with the crop for water and the small amount of remaining nitrogen. This is why the waterlogged parts of a paddock are often weedy, and require special attention if the yield potential is to be achieved. [51]

14.3 Other environmental issues

Triticale will grow on similar soils to wheat and barley, but is also adapted to soils that are too acid for the other cereals. It is relatively tolerant of boron, and is tolerant of high aluminium levels. On alkaline soils where other cereals are affected by manganese, zinc or copper deficiency, triticale is less affected. [52]

50 Queensland Government (2016) Improving drainage of crop land. Queensland Government, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/improving-drainage-crop-land

51 DAFWA (2015) Management to reduce the impact of waterlogging in crops. DAFWA, https://www.agric.wa.gov.au/waterlogging/management-reduce-impact-waterlogging-crops

52 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, http://www.farmtrials.com.au/trial/13801

14.3.1 Drought and heat stress

Long-term historical records indicate that our climate is becoming progressively warmer and dryer. This trend is expected to continue due to increased levels of greenhouse gases in the atmosphere, with dry seasons likely to become more frequent over southern Western Australia. [53]

Drought is one of the major environmental factors that reduce grain production in rain-fed and semi-arid regions of Australia (Photo 13). The direct effects of heat stress are estimated to cost grain growers nationally about $1.1 billion. Due to the effects of climate change, both heat stress and frost are likely to play an increasing role in the future and will require growers to take steps to manage the risks. [54]

Photo 13: *Drought conditions in 2015 left a dry landscape prone to dust storms.*

Photo: Brad Collis, Source: GRDC.

Triticale has been variably rated for its resilience in drought, with one study ranking cereal in terms of highest-yielding in drought conditions as, in descending order, barley, complete triticale, durum wheat, bread wheat, substituted triticale, and oats. [55] Triticale is well adapted to conditions of limited water supply.

Overseas data indicates that in dry conditions triticale's biomass production falls, but that the biomass of wheat normally falls much further, so triticale's relative advantage is likely to become more pronounced during droughts. In a study in a Mediterranean climate, researchers found that the yield of wheat dropped significantly (by 25%, 54%, and 87%) under drought stress, while the yield of triticale showed only a slight and insignificant decrease (by 8%), compared to an irrigated control. It is suggested that the greater drought resistance of triticale can be attributed to the earliness of its heading, and to the greater capacity of its roots to extract water from the soil. [56]

In another study, in 1988–89 in Mexico, 24 early triticale lines were tested under drought stress (mean yield of 1,720 kg/ha) and with no stress (mean yield of 7,180 kg/ha), and compared with the best standard wheat cultivar available. Under drought conditions, triticale had a yield advantage over wheat. [57]

53 DAFWA (2016) Drought. DAFWA, https://www.agric.wa.gov.au/climate-land-water/climate-weather/drought

54 R Barr (2016) Diversity the key to balancing frost heat risks. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks

55 C López-Castañeda, RA Richards (1994) Variation in temperate cereals in rainfed environments II. Phasic development and growth. Field Crops Research, 37 (1), 63–75.

56 F Giunta, R Motzo, M Deidda (1993) Effect of drought on yield and yield components of durum wheat and triticale in a Mediterranean environment. Field Crops Research, 33 (4), 399–409.

57 A Blum (2014) The abiotic stress response and adaptation of triticale: a review. Cereal Research Communications, 42 (3), 359–375.

In 2009, laboratory experiments indicated that the varieties Tickit and Credit were able to accumulate more carbohydrates (sugars) in their stems, and to translocate them to the grain compared with varieties such as Everest and Kosciusko. The better translocation capacity may be related to improved drought tolerance. More detailed field assessment of water relations in triticale compared with wheat is needed, especially with the likelihood of drier conditions associated the current projections on climate change. [58]

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 stressors such as drought and frost. Controlled-environment studies have established that a 3–5% reduction in the grain yield of wheat can occur for every 1°C increase in average temperature above 15°C. Field data suggest that yield losses can be 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.

Plants are more sensitive to elevated temperatures during the reproductive stages of growth, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seedset, reduced duration of grainfill, and reduced grain size, all of which lead, ultimately, to reduced grain yield. Elevated temperatures are a normal, largely unavoidable occurrence during the reproductive phase of Australian crops in September and October. [59]

In some cereals, heat stress can be identified by the withering and splitting of leaf tips (Photo 14). The tips can also turn brown to grey in colour. In this situation, some or all grains fail to develop in a panicle. [60]

Photo 14: *Withered and split tips in heat-stressed cereal.*

Source: DAFWA

Managing drought and heat stress

Key points:

- Heat stress is a key yield limiting factor in crop production.
- Heat stress has been shown to adversely affect yield as early as GS 45.
- Post-flowering heat stress is most common in southern Australia.

58 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

59 P Telfer, J Edwards, H Kuchel, J Reinheimer, D Bennett (2013) Heat stress tolerance of wheat. GRDC Update Paper. GRDC, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Heat-stress-tolerance-of-wheat

60 DAFWA (2016) Diagnosing heat stress in oats. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-heat-stress-oats

- Delayed sowing increases the chance of the crop being exposed to heat stress, particularly at the vulnerable pre-flowering growth stages.

Because drought can be unpredictable and can last for extended periods of unknown length, it is difficult to prepare for it. See the links below for some tips on managing drought.

The results of recent research in southern Australia suggest that variety selection and early sowing are still the most effective means to reduce the risk of a crop being damaged by excessive heat. A later-sown crop has a greater likelihood of being exposed to the heat stress at more sensitive growth stages, particularly pre-flowering, and will have greater consequences on grain yield. [61]

In drought, it is important to not ignore the signs and to have a plan, act early, review and then plan again, and revise the plan with each action as you play out your strategy.

Step One: Check the most limiting farm resources:

- funds available;
- surface/subsoil moisture for crop leaf and root growth;
- need to service machinery – breakdowns cost time, money and frustration.

Step Two: Set action strategies, considering:

- breakeven position of each strategy chosen;
- windows of opportunity to adopt management practices that will be profitable during drought;
- available resources and the implications for ground cover, chemical residues, etc., of carrying out each strategy;
- when situations are changing, conditional and timely fall-back options.

Step Three: Monitor and review performance, position and outlook by:

- using your established network to stay informed about key factors that affect your drought strategies;
- being proactive about the decisions made;
- being prepared for change;
- remembering that the impact falls very heavily not only on the decision makers but on the whole farm family. [62]

MORE INFORMATION

Make sure the impact of herbicide residues following drought is considered.

Winter cropping following drought

Soil management following drought

NSW DPI, Drought Hub

Drought planning

Soil management following drought

The principal aim after rain should be to establish either pasture or crop as a groundcover on your bare paddocks as quickly as possible. This is especially important on the red soils, but is also important for the clays. After drought, many soils will be in a different condition to what is considered to be their 'normal' condition. Some will be bare and powdery on the surface, some will be further eroded by wind or water, and some will have higher levels of nitrogen (N) and phosphorus (P) than expected. Loss of effective ground cover (due to grazing or cultivation) leaves the soil highly prone to erosion by wind and water. Research by the former Department of Land and Water Conservation's Soil Services showed that erosion due to drought-breaking rain can make up 90% of the total soil loss in a 20–30 year cycle. Following a drought, available N and P levels in the soil are generally higher than in a normal season. However, most of the N and P is in the topsoil, so if erosion strips the topsoil much of this benefit is lost. [63]

61 P Telfer, J Edwards, D Bennett, H Kuchel (2013) Managing heat stress in wheat. Mallee Sustainable Farming, http://www.msfp.org.au/wp-content/uploads/Managing-heat-stress-in-wheat.pdf

62 Meaker G, McCormick L, Blackwood I. (2007). Primefacts: Drought planning. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/96236/drought-planning.pdf

63 Jenkins A. (2007). Primefacts: Soil management following drought. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0012/104007/soil-management-following-drought.pdf

14.3.2 Aluminium toxicity

At soil pH levels of below 5, aluminium (Al) and manganese (Mn) become available in soil solution, and can damage root growth and reduce yields. Screening work in flow-culture systems and field observations has indicated that triticale has a range of tolerances to aluminium. For example, Tahara is highly Al-tolerant, while Empat, an older grazing-and-grain type, had much poorer Al-tolerance. [64]

Triticale grows productively on acidic soils where the high availability of aluminium ions reduces the economic yield of many other crops. [65]

Many triticale cultivars are able to grow better than wheat in soils with high aluminium toxicity. [66]

Many of the new varieties have now been screened in flow culture for Al tolerance (Table 5). [67] In the screening system, small plants are given an aluminium stress in solution and afterwards examined for root regrowth. The presence of regrowth and its length indicate relative tolerance, with greater length of regrowth being a measure of greater Al tolerance. As expected, the wheat variety (Janz) had poor Al tolerance, rye showed a good tolerance, and the triticales showed a range of tolerances, with Canobolas⟮D⟯ being the most Al-tolerant variety. [68]

Table 5: *Aluminium tolerance of newer triticales.*

Variety	Re-growth length (mm)
Wheat	2.4
Rye	40.6
Tobruk⟮D⟯	21.0
JCRT 74	29.5
JCRT 75	30.8
Breakwell⟮D⟯	36.5
Tahara	35.1
AT528	27.6
H20	27.6
H55	39.6
H116	29.5
Bogong⟮D⟯	29.5
H128	35.4
H157	29.5
H249	32.8
Canobolas⟮D⟯	46.1
H426	48.7

Source: Jessop and Fittler 2009)

Many of the yellow earths in the Western Australian wheatbelt have naturally acidic subsoils that can reduce the yield of wheat grown on them. In WA, the major problem

64 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

65 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/docrep/009/y5553e/y5553e00.htm

66 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/docrep/009/y5553e/y5553e00.htm

67 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

68 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Trethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

when soils acidify is aluminium toxicity in the subsurface soil. Low pH in topsoils primarily affects nutrient availability, and decreases nodulation of legumes and nitrogen fixation in pastures. These problems are minimised if the topsoil pHCa is maintained above 5.5.

In most wheatbelt soils, aluminium will reach toxic levels when subsurface pHCa falls below 4.8. Generally, there is sufficient organic matter in topsoil that aluminium can remain bound and does not become toxic to plant roots, even though it is extractable in a laboratory analysis. [69]

69 DAFWA (2016) Effects of Soil acidity. DAFWA, https://www.agric.wa.gov.au/soil-acidity/effects-soil-acidity

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.

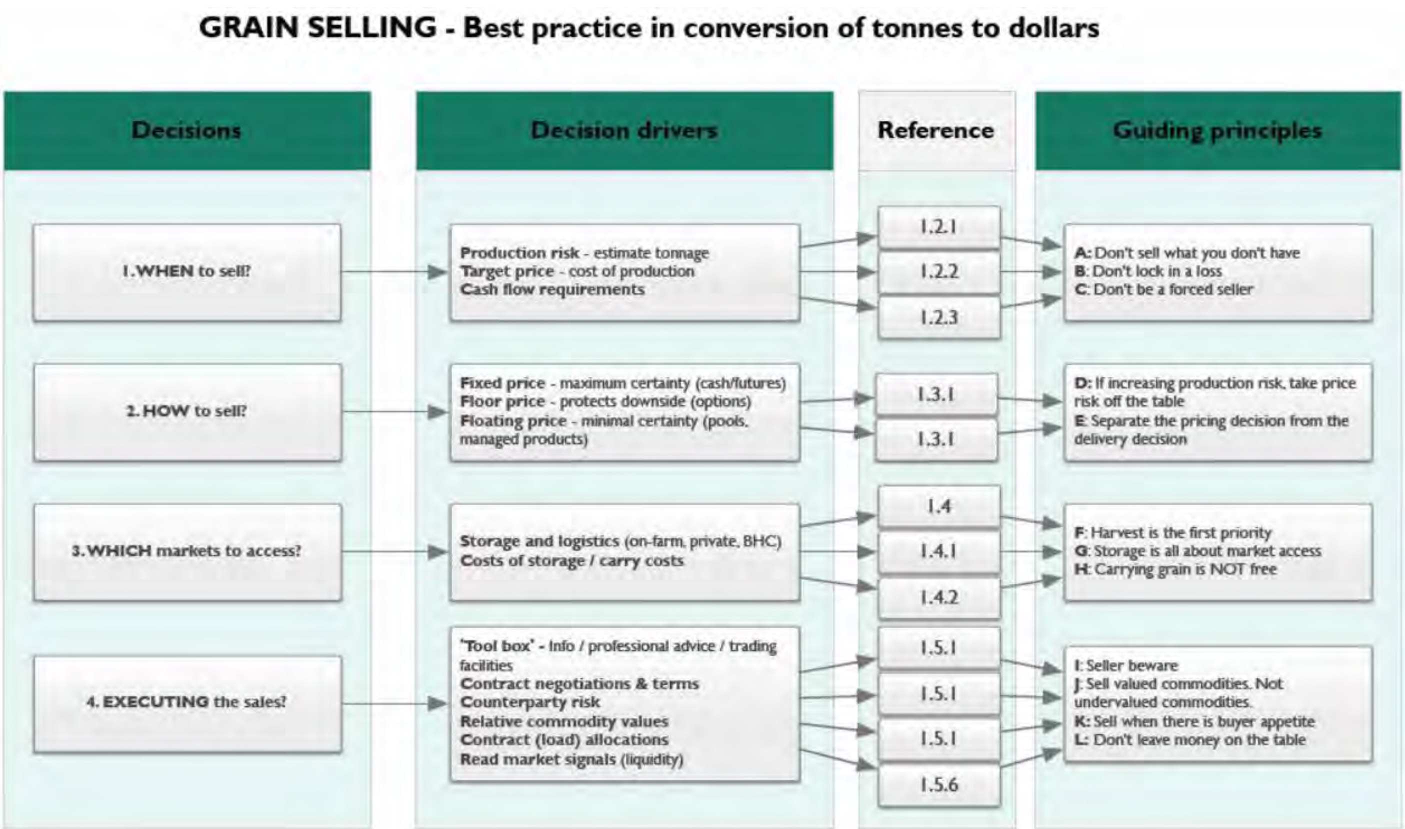

Figure 1: *Grain selling flow chart*

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

References are made to the section of the GrowNote you will find the detail.

15.1 Western feed grains – market dynamics and execution

15.1.1 Price determinants for Western Australian feed grains

Stock feed markets are the biggest consumers of grain domestically in Australia. Whilst the majority of the grain produced in WA is exported, the domestic stock feed market consumes 600kt of feed grain per annum, representing ~5% of total Australian stock feed consumption and approximately 5% of average WA's winter grain production.

Whilst the Western Australian stock feed market is small relative to the rest of Australia it is growing as intensive pig and poultry industries in particular expand their WA foot print. This trend is being driven by the availability of land, the regulatory environment and the availability of feed grains.

The largest market for stock feed in WA is the poultry market including eggs and chicken meat accounting for 30%, followed by pig meat production, dairy, beef and then sheep industries.

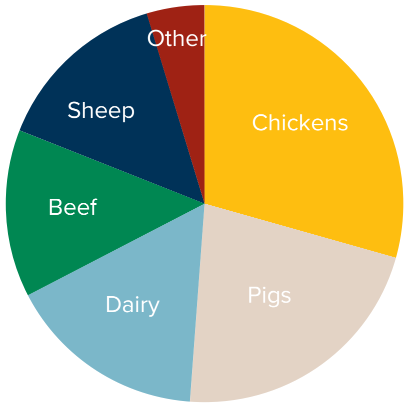

Figure 2: *Sources of demand for stock feed in Western Australia*

The key drivers of prices for feed grains in Western Australia include;

- Rate of exports and remaining supply of feed grains for domestic markets.
- Commodity prices in the consuming industry (ie meat prices)
- Consumption trends in domestic livestock markets.
- Livestock health
- Number of animals on feed.
- Seasonality / supply of pasture and fodder vs grains.
- Imports of alternate feed sources (ie soy bean meal)
- Rate of live export of sheep from WA.
- Prices of competing feed grains.

Demand for grain from stock feed markets tends to be steady throughout the year. However knowing there is strong competition from the export market for WA grain, some buyers will seek to secure requirements shortly after harvest when the supply of grain is more certain.

15.1.2 Executing tonnes into cash

When it comes to accessing domestic stock feed markets there are several ways this can be approached.

1. Sale to a feed miller or manufacturer
2. Sale direct to farm or end user.
3. Sale to a trader or merchant who on sells this grain to the stockfeed market.

Each organisation will differ in terms of how they manage grain purchases, the professionalism of the enterprise and management around grain requirements and grain purchases, documentation and record keeping.

Hence it is particularly prudent when making sales into these markets to be vigilant in maintaining records of contracts, even when they are executed by phone. It is strongly advised that the seller keeps a written record of the particulars of the contract including price, quantity, quality, delivery and payment terms to protect yourself in the event of a dispute with your counterparty as to the details of the sale agreement.

It is even better practice to send a contract confirmation to the buyer in the event they don't provide one to you, or even as well as. Grain Trade Australia provide standard form contract documents which can be completed by either party and returned to the buyer by email as confirmation of the verbal contract. This way, any mis-understandings that may have taken place on the phone can be quickly identified and rectified immediately whilst the conversation is still fresh in both your minds rather than waiting until delivery to identify a problem.

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:

- Price - Future price is largely unpredictable hence devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.
- Quantity and Quality -When entering a cash contract you are committing to delivery of the nominated amount of grain at the quality specified. Hence production and quality risk must be managed.
- Delivery terms -Timing of title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end users it relies on prudent execution management to ensure delivery within the contracted period.
- Payment terms- In Australia the traditional method of contracting requires title of grain to be transferred ahead of payment; hence counterparty risk must be managed.

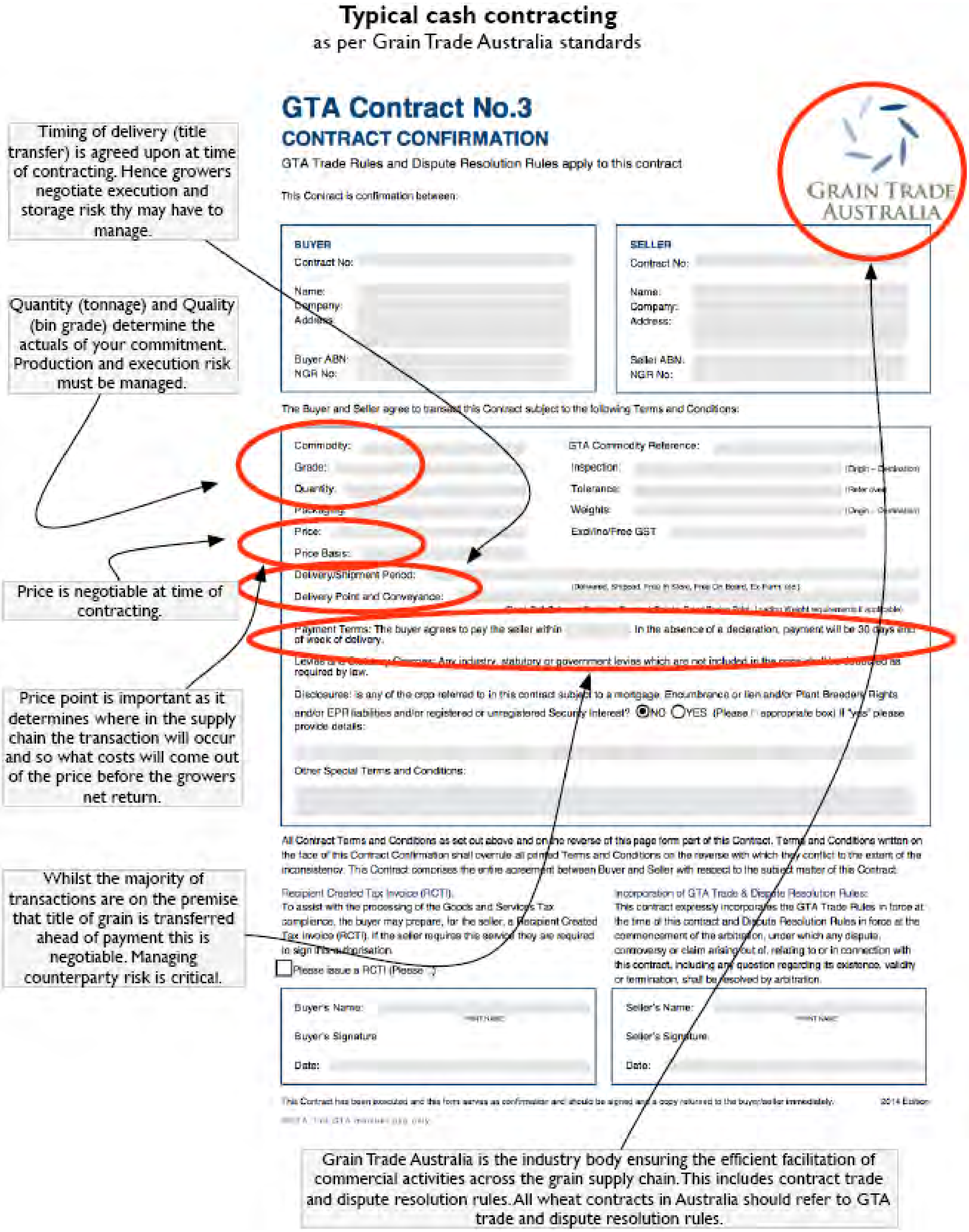

Figure 3: *Typical cash contracting*

Counterparty risk

Most sales involve transferring title of grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: “Seller beware” – 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.
- Conduct a credit check (banks will do this) before dealing with a buyer they are unsure of.
- Only sell a small amount of grain to unknown counterparties.
- Consider credit insurance or letter of credit from the buyer.
- Never deliver a second load of grain if payment has not been received for the first.
- Do not part with title of grain before payment or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting, alternatively the Clear Grain Exchange provides secure settlement where-by the grower maintains title of grain until payment is received by the buyer, and then title and payment is settled simultaneously.

Above all, act commercially to ensure the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving $5/t more and not getting paid is a disastrous outcome.

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 that interested in buying the commodity.

Principle: “Sell when there is buyer appetite” – When buyers are chasing grain, growers have more market power to demand a price when selling.

Buyer appetite can be monitored by:

- The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate buyer appetite is strong. However if there is one buyer $5/t above the next best bid, it may mean cash prices are susceptible to falling $5/t if that buyer satisfies their buying appetite.
- 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.

Know the specifications of your grain

- Feed ‘grades’ of grain as defined by bulk handler receival standards can have very broad quality specifications. For the lowest grades there is often no minimum tolerances on screenings or protein hence no two parcels are the same.
- The important factor for the stock feed market however is not what ‘grade’ the grain is but its energy and protein components which ultimately determine conversion in to meat or other animal products. Hence by having your grain tested and knowing your specifications helps the buyer to know exactly what the value of the grain will be in the production system.
- Without this information the buyer may base their pricing on the ‘minimum’ specification or likely worst case scenario, to protect themselves in the event they receive grain of the lowest quality allowable in the grade specifications. However knowing why your grain was downgraded and the specifications of

the load, the buyer may be able to pay premiums for the exact quality you are offering, above the minimum specification.

15.1.3 Ensuring access to markets

Planning on where to store the commodity is important in ensuring access to the market that is likely to yield the highest return.

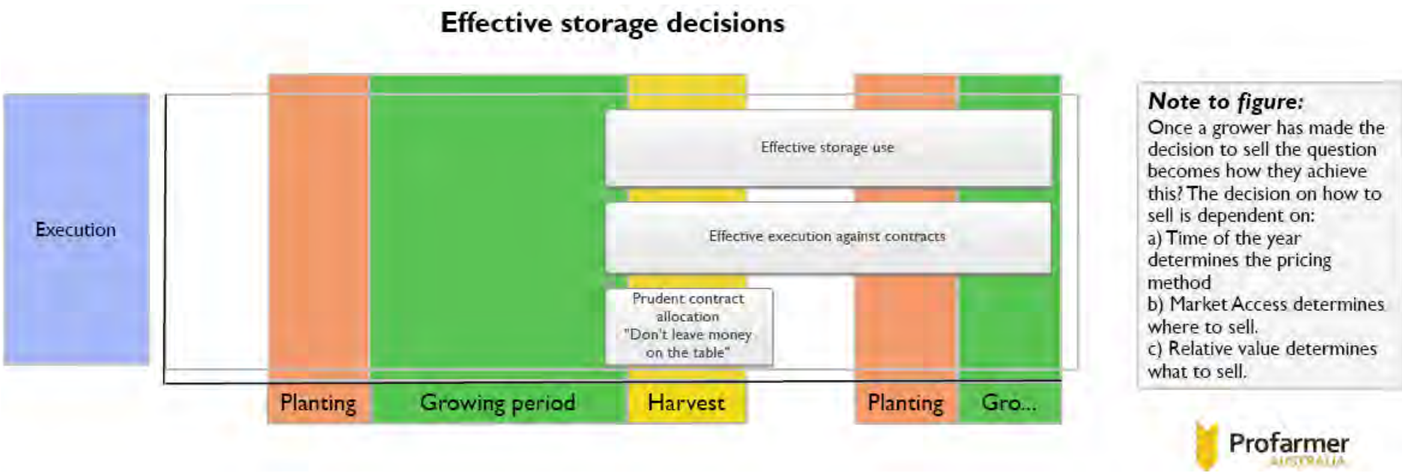

Figure 4: *Effective storage decisions*

Storage and Logistics

Return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access to maximise returns as well as harvest logistics.

Storage alternatives include variations around the bulk handling system, private off farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity.

Commodities destined for the domestic end user market, (e.g feed lot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on-farm requires prudent quality management to ensure delivery at agreed specifications and can expose the business to high risk if this aspect is not well planned. Penalties for out-of-specification grain on arrival at a buyer's weighbridge can be expensive. The buyer has no obligation to accept delivery of an out-of-specification load. This means the grower may have to incur the cost of taking the load elsewhere whilst also potentially finding a new buyer. Hence there is potential for a distressed sale which can be costly.

On-farm storage also requires prudent delivery management to ensure commodities are received by the buyer on time with appropriate weighbridge and sampling tickets.

Principle: "Storage is all about market access" – Storage decisions depend on quality management and expected markets.

MORE INFORMATION

For more information on on-farm storage alternatives and economics refer Section 13. Grain Storage.

For more information on on-farm storage alternatives and economics refer GRDC Western Region - Wheat - GrowNote, Section 13 Grain Storage

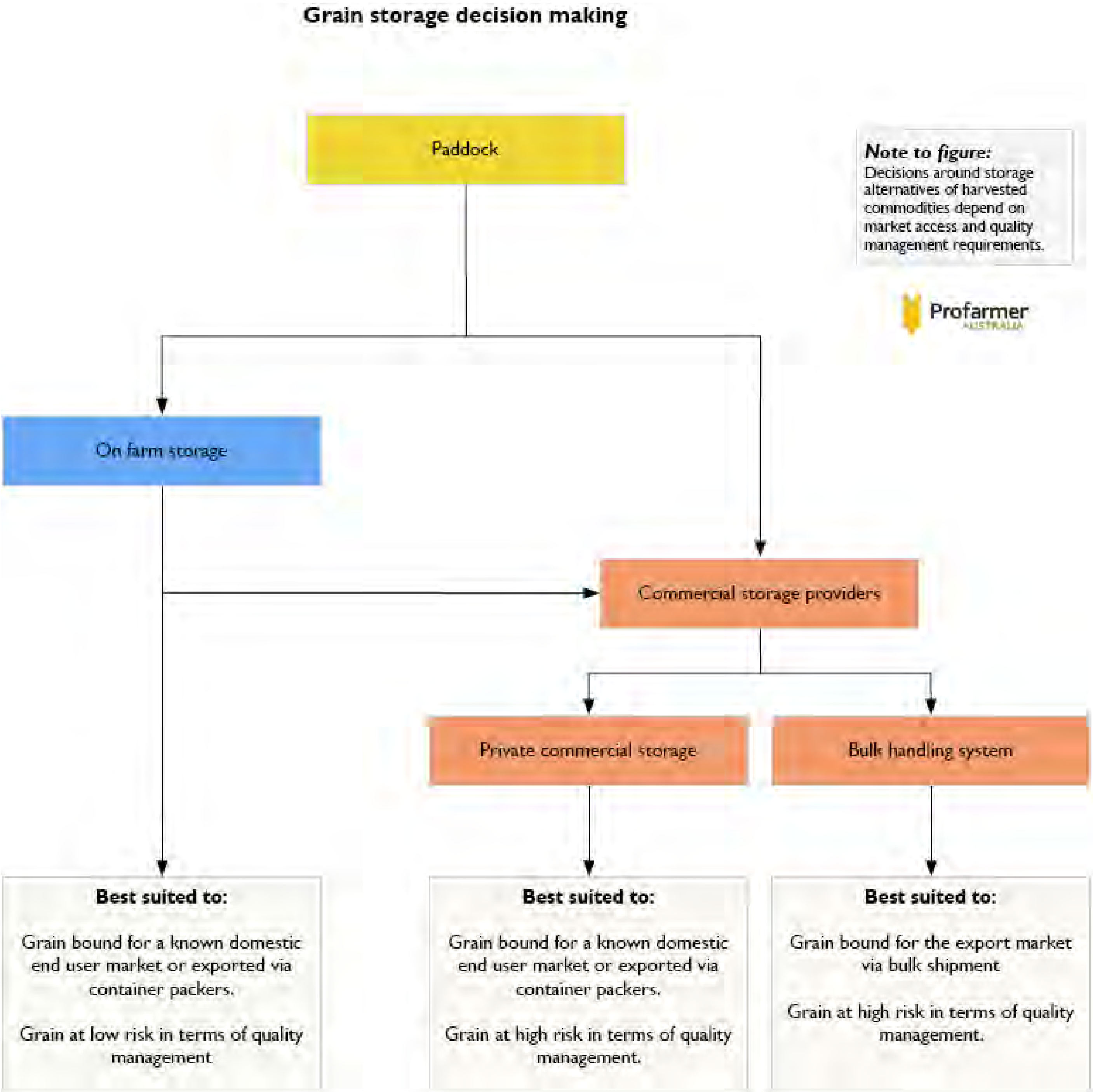

Figure 5: *Grain storage decision making*

Separate the delivery decision from the pricing decision

Organised stock feed buyers, with a clear out look as to what their grain requirements will be across the season may seek to purchase their grain in advance of delivery. That is they may purchase grain in March for delivery between May and July. This provides the seller the opportunity to obtain price certainty immediately whilst delivery may not take place until some point in the future.

The benefit of this is that a seller can capture strong value when it presents, even though it may not be a convenient time to arrange delivery. Or you can create cash flow certainty for a known future commitment at today's price.

Cost of carrying grain

Storing grain to access sales opportunities post-harvest invokes a cost to "carry" grain. Price targets for carried grain need to account for the cost of carry.

Carry costs for canola are typically $4-5/t per month consisting of:

1. monthly storage fee charged by a commercial provider (typically ~$1.50-2.00/t per month)
2. the interest associated with having wealth tied up in grain rather than cash or against debt (~$2.50-$3.00/t per month depending on the price of the commodity and interest rates.

The price of carried grain therefore needs to be $4-5/t per month higher than what was offered at harvest.

The cost of carry applies to storing grain on farm as there is a cost of capital invested in the farm storage plus the interest component. $4-5/t per month is a reasonable assumption for on farm storage.

Principle: "Carrying grain is not free" – The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy.

Principles revised

1. "Always keep written records" – thorough record keeping is everyone's responsibility not just the buyers.
2. "Seller beware" – Know your counterparty
3. "Know your specs" – grades don't always convey quality
4. "Separate the delivery decision from the pricing decision"
5. "Sell when there is buyer appetite" – When buyers are chasing grain, growers have more market power to demand a price when selling.
6. "Storage is all about market access" – Storage decisions depend on quality management and expected markets.
7. "Carrying grain is not free" – The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy.

Current and past research

Project Summaries
www.grdc.com.au/ProjectSummaries

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 www.grdc.com.au/ProjectSummaries

Final Report Summaries
http://finalreports.grdc.com.au/final_reports

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

Online Farm Trials
http://www.farmtrials.com.au/

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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