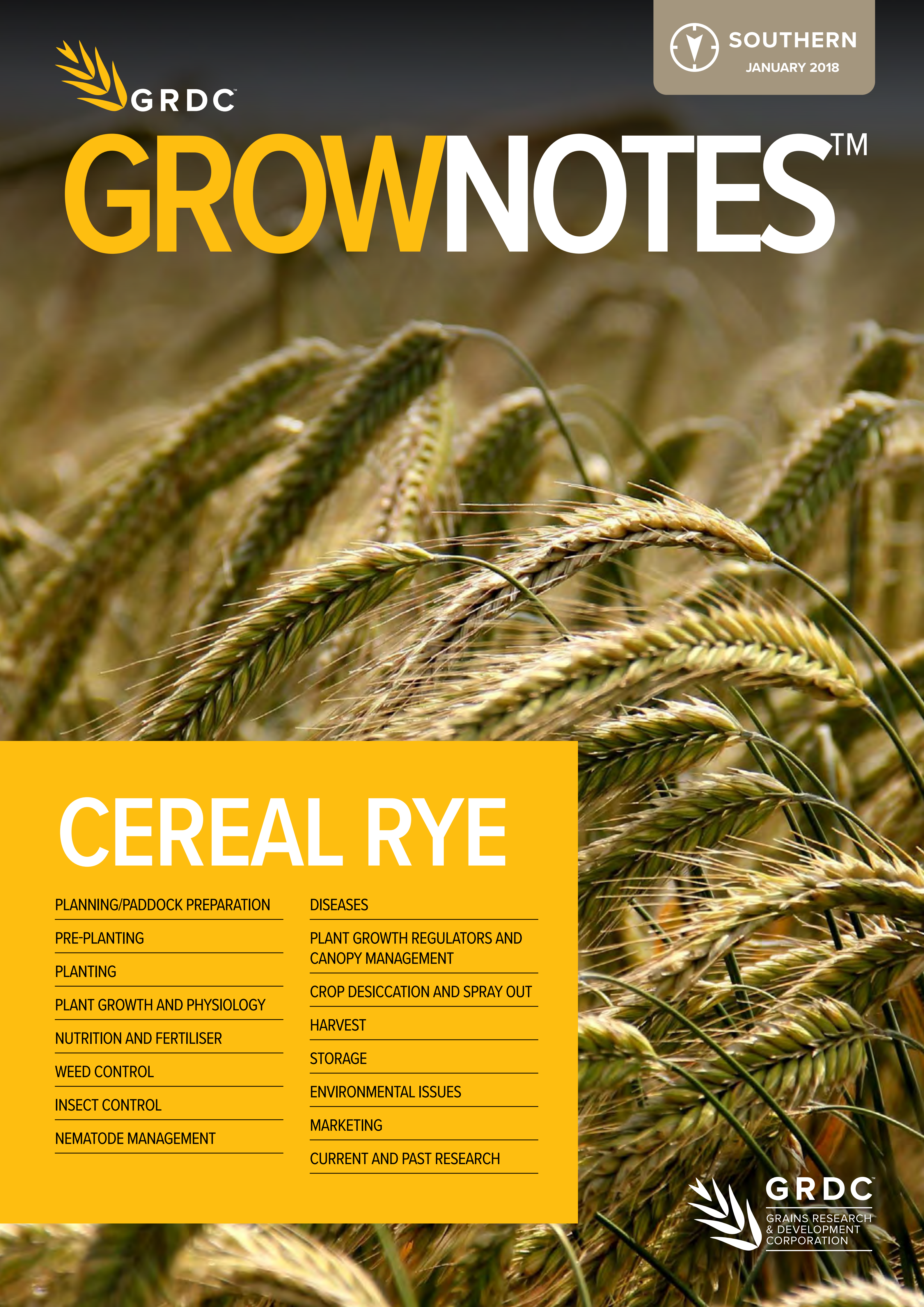


SOUTHERN
JANUARY 2018

GRDC

GROWNOTES™

CEREAL RYE

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

ISBN: 978-1-921779-07-7

Start here for answers to your immediate cereal rye crop management issues

What end-use options are available in cereal rye?

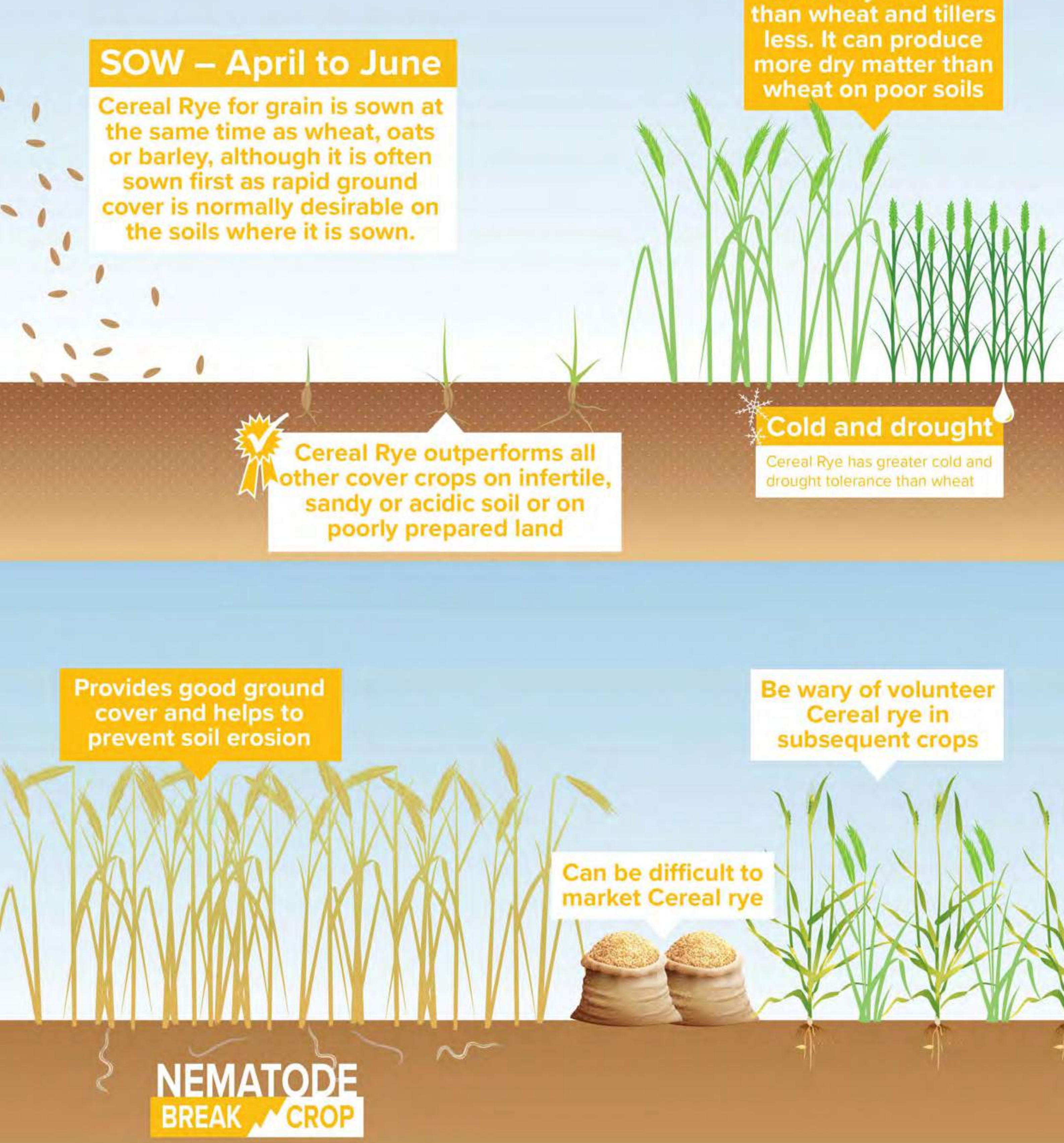
Which diseases are a problem in cereal rye?

How can I limit volunteer rye in subsequent crops?

Can cereal rye be sown early?

Does cereal rye require additional fertiliser?

Tips for cereal rye cropping



Contents

Introduction

7 Insect control

Introduction

A.1 Crop overview

Cereal rye (*Secale cereal,* Photo 1) is a grass grown extensively as a grain, a cover crop and a forage crop. It is a member of the wheat tribe (Triticeae) and is closely related to barley (genus *Hordeum*) and wheat (*Triticum*). Rye is a comparatively modern cereal, first cultivated in northern Europe. It is thought to have originated from wild types of rye, which are weeds in wheat crops in Asia Minor.

Photo 1: *Cereal rye grain heads.*

Source: PlantVillage

A.1.1 Comparative notes

- Rye is more cold- and drought-tolerant than wheat.
- Oats and barley do better than rye in hot weather.
- Rye is generally taller than wheat and tillers less. It can produce more dry matter than wheat on poor soil under drought conditions and on light-textured soils but is harder to break down than wheat or triticale.
- Rye is a better soil renovator than oats, but brassicas and Sudan grass (*Sorghum × drummondii*) provide deeper soil penetration.
- Brassicas generally contain more nitrogen than rye. They scavenge nitrogen nearly as well as rye and, because they decompose more rapidly, are less likely to tie it up. [1]

A.1.2 Description

Rye has an erect, slender stem topped with a curved spike 7–15 cm long (Photo 2). The head is made up of individual spikelets, each with two florets that produce one or two kernels. The spikelets are arranged alternately along the length of the head. The leaves of the plant grow from nodes on the stem and are lance-like blades, blue-green in colour. Rye can reach up to three metres in height and it is grown either as an annual (spring rye) or as a biennial (winter rye) (Table 1). [2]

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1 A Clark (Ed.) (2007) Managing cover crops profitably. 3rd edn. Sustainable Agriculture Network, Beltsville, MD, http://mccc.msu.edu/wp-content/uploads/2016/08/ManagingCCProfitably.pdf

2 Plant Village (2015) Cereal rye. Penn State University, EPFL, https://www.plantvillage.org/en/topics/rye/diseases_and_pests_description_uses_propagation

Photo 2: *The rye seed head (left) is slender, longer and somewhat nodding compared with the wheat seed head (right).*

Source: NebGuide

Table 1: *Characteristics differentiating wheat from rye.*

Characteristic	Wheat	Rye
Stems	Erect and freely branching at base, 60–100 cm tall	Larger and longer than wheat
Leaves	Blade 1–2 cm wide, usually dark green	Coarser and more bluish than wheat
Ligules	Membranous with an irregular edge fringed with minute hairs	Membranous, short and somewhat rounded
Auricles	Purple changing to white, sharply curved and always present	White, narrow, and withers early
Seed head	5–13 cm long, oblong or elliptical in shape	Slender, longer than wheat, and somewhat nodding
Seed	Roughly egg-shaped and light brown to darker red	Narrower than wheat and usually brownish olive to yellow

Source: NebGuide

Rye grain is smaller and darker than wheat, is harder to mill, and produces a lower percentage of flour. Hectolitre (hL) weight is normally about 70–75 kg, with a minimum of 70 kg/hL and maximum moisture of 12% for marketing purposes. Grain protein tends to be slightly lower than that of wheat. The dough lacks the elastic properties of wheaten dough. Bread made from rye flour has a close texture and a slight ‘tang’.

Rye is a winter–spring cereal, with a growing period similar to the main winter–spring cereals, wheat, oats and barley. Sowing is from mid-March to mid-May and harvesting from November to January.

Rye withstands adverse conditions better than other cereals. It can stand cold and limited waterlogging. More importantly, its drought resistance and ability to withstand sand blast enables it to produce a soil-binding cover on land where other cereals will not grow. Under conditions where wheat, oats or barley will grow only a few centimetres high or they may even be completely blown away, rye often will grow vigorously and reach a height of one metre or more. [3]

In Victoria and South Australia, most rye is harvested for grain, and in New South Wales, it is used mainly for grazing. [4]

3 Agriculture Victoria (2013) Growing cereal rye. State Government Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

4 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

MORE INFORMATION

Ryegrass Covercrop.com: Annual ryegrass or cereal rye?

Cereal rye should not be confused with the aggressive weed annual ryegrass (*Lolium rigidum*).

A.1.3 Rye for human consumption

Rye grain is used for flour, rye bread, rye beer, crisp bread, some whiskeys, some vodkas, and animal fodder. It can also be eaten whole, either as boiled rye berries or by being rolled, similar to rolled oats. Cereal rye is very distinct from wheat for bread making; the dough lacks elasticity and gas retention properties. Used alone, it produces distinctive black bread. Rye flour is less responsive to yeast than wheaten flour. Lighter rye loaves are produced from rye and wheat mixtures. Rye flour, rye meal and kibbled rye are all end-products (Photo 3). Rye flour and meal are used in rye bread and biscuits. Plump grain is highly sought after for kibbled rye manufacture. [5]

Photo 3: *Wholegrain rye flour (left) and kibbled rye (right) milled for human consumption.*

Source: Blue Lake Milling

A.1.4 Rye for animal consumption

Cereal rye can be grazed. When used as grazed forage, cereal rye is usually mixed with other cool-season species such as triticale. Rye can be cut for hay at the early heading stage of development. [6] Cereal rye should be mixed with other grains when fed to monogastrics, especially chickens. It has a high content of soluble pentosans (a class of polysaccharide), which can cause decreased weight gain and sticky droppings in chickens. [7]

Grain

Rye grain has a feeding value ~85–90% that of maize, and contains more digestible protein and total digestible nutrients than oat or barley. Rye is most satisfactorily used when mixed with other grains at a proportion less than one-third, because it is not highly palatable and is sticky when chewed. [8]

One study compared the effectiveness of rye grain and wheat grain for feeding sheep. There was no significant difference in liveweight change between sheep fed rye and those fed wheat. Sheep with free access to grain (production group)

5 DPI NSW (2016) Winter crop variety sowing guide, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

6 NRCS (2012) Cereal Rye plant guide. US Department of Agriculture, https://plants.usda.gov/plantguide/pdf/pg_sece.pdf

7 DPI NSW (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

8 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Alternative field crops manual: rye. University of Wisconsin, https://hort.purdue.edu/newcrop/afcm/rye.html

ate more rye than wheat. The reason is not known, but rye did not depress feed intake compared with wheat. Sheep offered maintenance rations ate all of the grain on the day it was fed. The results indicate that rye and wheat perform equally as maintenance and production rations for sheep. However, farmers should observe their sheep closely when first using rye grain. [9]

Forage

Rye makes excellent forage (Photo 4). For best quality, rye should be cut between early heading and the milk stage of growth. Rye matures earlier than wheat or triticale and has higher levels of crude protein. However, forage yields are lower, resulting in somewhat lower crude protein yields and overall lower relative feed values. Thus, the main advantages of winter rye as a forage compared with winter wheat or winter triticale are that it is more winter-hardy and reaches optimum harvest maturity 7–10 days earlier.

Photo 4: *Cattle grazing on cereal rye.*

Source: Progressive forage

Pasture

In the growth stage before heading, rye is used extensively as a pasture crop. Rye generally provides more forage than other cereals in late autumn and early spring because of its rapid growth and its adaptation to low temperatures. Although rye is a less palatable pasture crop, it is readily grazed when other green forages are not available. [10]

Rye does not recover as well as oats after grazing. Rye is not a suitable crop for hay. The hay is of poor quality because of the fibrous nature of the straw and the awns carried on the head. [11]

A.2 Growing regions

The Southern Region stretches from central New South Wales (south of Dubbo) through to Victoria, Tasmania and South Australia and the south-west corner of Western Australia. The rainfall pattern ranges from uniform in central New South Wales through to winter-dominant in Victoria, Tasmania, South Australia and the south-west of Western Australia.

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

9 B Ashton, D Rendell, A King (1992) The value of cereal rye as a grain for feeding sheep. Proceedings Australian Society of Animal Production, Vol. I9, http://www.asap.asn.au/livestocklibrary/1992/Ashton92.PDF

10 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Alternative field crops manual: rye. Purdue Agriculture, https://hort.purdue.edu/newcrop/afcm/rye.html

11 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

production. Summer crop production requires irrigation and the major field crop irrigated in this region is medium-grain rice in southern New South Wales.

Planting of the winter crop depends on 'opening rains' and usually begins in May and can continue through until late July. The winter crop harvest can begin in late October and continue through until January in the higher rainfall areas. [12]

The Mallee region comprises 7 million hectares (Mha) of land, three-quarters of which is allocated to dryland agriculture. The Mallee stretches from Penong in South Australia to Kerang in Victoria (Figure 1).

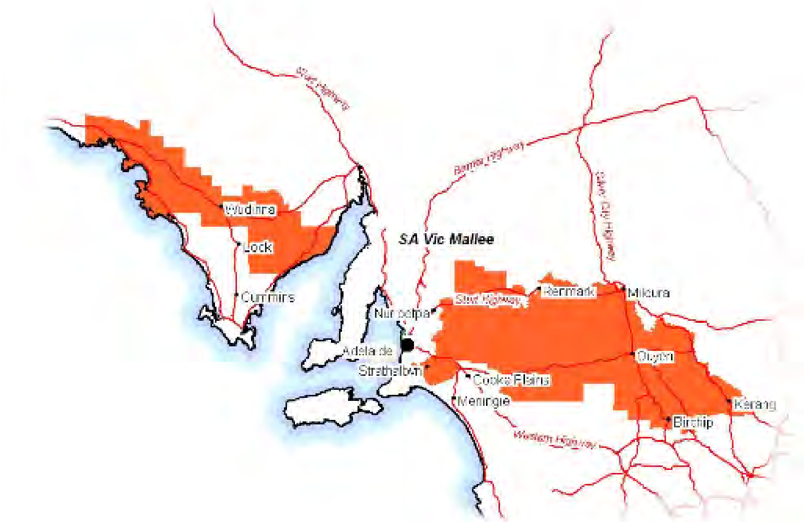

Figure 1: *South Australia–Victoria Mallee Agroecological Zone.*

Source: UWA

Crops suitable for growing in the South Australia–Victoria Mallee region during the winter are cereal rye, wheat, barley, oats, triticale, lupins, vetch, canola, field peas, lentils, chickpeas, faba beans and safflower. [13]

Rye is grown mainly in southern Australia, where its principal use was for stabilising drifting soils or for grazing. Grain production in South Australia represents ~70% of the Australian crop, with 7,500 tonnes (t) produced across 6,200 ha in the 2015–16 season (Table 2). [14] Although South Australia is the largest producer of cereal rye in Australia, rye makes up only a small proportion of South Australia's grain industry (Figure 6).

Table 2: *Rye crop estimates against five-year average.*

Year	2010–11	2011–12	2012–13	2013–14	2014–15	5-year average	2015–16
Area sown (ha)	9500	9500	9500	7100	9000	8900	7500
Quantity produced (t)	11600	7900	7500	6350	9300	8500	6200

Source: PIRSA

12 AEGIC (2016) Australian grain production—a snapshot. Australian Export Grains Innovation Centre, http://aegic.org.au/australian-grain-production-a-snapshot/

13 A Greijdanus, M Kragt (2014) The Grains Industry: An overview of the Australian broad-acre cropping. Working Paper 1402, School of Agricultural and Resource Economics, UWA, http://ageconsearch.umn.edu/record/164256/files/WP1400002.pdf

14 PIRSA (2016) Crop and pasture report South Australia, 2015–16 summary and final estimates. Primary Industries and Regions SA, http://pir.sa.gov.au/__data/assets/pdf_file/0006/276297/2015_16_Crop_and_Pasture_Report_Summary_and_final_Estimates.pdf

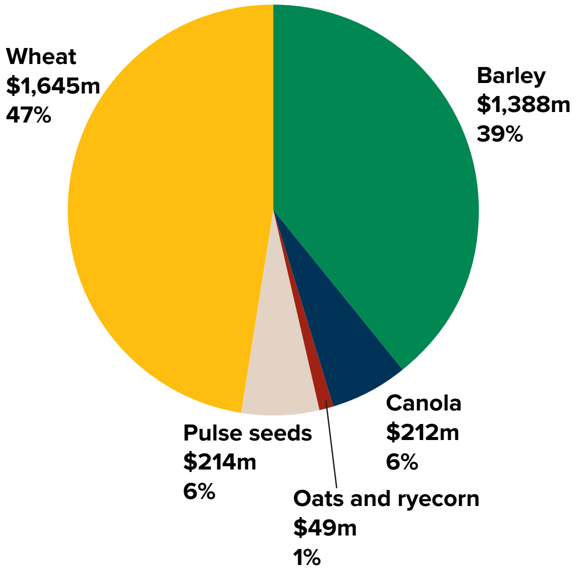

Figure 2: *South Australian gross revenue from field crops 2009–10.*

Source: PIRSA

In Victoria, ~85% of the area sown to rye is in the Mallee region. Its main use now is to produce large plump grain for the milling industry, particularly for the crisp bread and multigrain bread industry. The average yield in Victoria varies from 0.4 to 1.8 t/ha. [15]

A.3 Brief history

Domesticated rye occurs in small quantities at a number of Neolithic sites in Turkey, such as PPNB Can Hasan III, but is otherwise virtually absent from the archaeological record until the Bronze Age of Central Europe, circa 1800–1500 BCE. It is possible that rye travelled west from Turkey as a minor admixture in wheat, and was only later cultivated in its own right. Since the Middle Ages, rye has been widely cultivated in Central and Eastern Europe and is the main bread cereal in most areas east of the French–German border and north of Hungary. [16]

Globally, the area of cultivated land dedicated to growing rye has decreased substantially since the 1970s. In 1986, the area harvested was 24 Mha. By 1996, this had declined to only 17 Mha, a 29% drop. The decrease in cultivated area was largely offset by an increase in yield. Yields during the late 1960s were as low as ~520 kg/ha. During the 1990s, yields were ~820 kg/ha, an increase of 57%. This significant increase was achieved through improvement in agronomic practices, especially the use of chemical fertilisers and crop rotation, a reduction in the use of less fertile land, and development of high-yielding cultivars. [17]

Early cropping of cereal rye in Australia was recorded in 1804 in colonial Tasmania. Thought to be one of the hardiest cereals, 2.25 acres of rye was sown in 1804 and 1805. Thereafter any significance it might have had in the colonial economy has been lost, with acreages not recorded. [18]

15 Agriculture Victoria (2013) Growing cereal rye. State Government Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

16 D Zohary, M Hopf, E Weiss (2012) Domestication of plants in the Old World: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin. p. 62. Oxford University Press, https://books.google.com.au/books?id=1hHSYoqY-AwC&pg=PA62&redir_esc=y&hl=en#v=onepage&q&f=false

17 W Bushuk (2001) Rye production and uses worldwide. Cereal Foods World, http://www.agmrc.org/media/cms/bushuk_C8B79BAB55BB0.pdf

18 S Morgan (2003) Land settlement in early Tasmania: creating an antipodean England. Cambridge University Press.

Demand for cereal rye has been static for a number of years with domestic consumption ~25,000 t/year. Local use for rye is mainly in the form of kibbled rye or cracked grain for use in mixed grain breads or for breads requiring more fibre. Demand has also increased, but to a lesser extent, for sourdough rye bread, rye flour and rye meal.

Production in Australia is generally erratic, with supply and demand very elastic and price-sensitive (Figure 3). Seasonal production is greatly influenced by seasonal conditions and the soil type and topography on which rye is usually grown. [19] Australia annually imports ~10,000 t of rye to guarantee a regular supply.

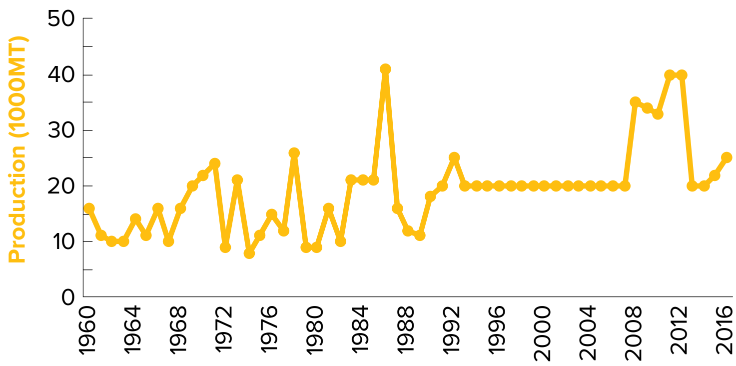

Figure 3: *Australian rye production by year.*

Source: indexmundi

19 Agriculture Victoria (2013) Growing cereal rye. State Government Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Planning/Paddock preparation

Key messages:

- Relatively inexpensive and easy to establish, cereal rye (*Secale cereale*) outperforms all other cover crops on infertile, sandy or acidic soil or on poorly prepared land. It is widely adapted, but grows best in cool, temperate zones such as in southern Australia.
- Rye prefers light loams or sandy soils and it will germinate even in quite dry soil. It also will grow in heavy clays and poorly drained soils, and some cultivars tolerate waterlogging.
- The optimum pH($CaCl_2$) for rye growth is ~4.5–7.5. [1] It is also tolerant of high levels of aluminium (Al). [2]
- Rye can establish in very cool weather. It will germinate at temperatures as low as ~1°C. Vegetative growth requires temperatures of 3°C or higher. [3]
- Rye is used for early sowings as a dual-purpose cereal, providing abundant, quick, early stock feed and as a grain-only crop, and for erosion control. [4]
- Cereal rye is adapted to all soils; however, its major fit is on the lighter acid soils where yields are usually 70–100% of wheat and triticale yields when sown between May and June. [5]

1.1 Paddock selection

1.1.1 Topography

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 account for most of the variations in plant-available N.

Potential environmental and economic benefits are gained from 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 infertile slopes, where legumes bring the needed N inputs and rye does not result in substantial N reductions; all cover crops contribute to erosion control and carbon sequestration in such terrain. On the other hand, if N leaching is the major concern, a rye cover crop can be particularly advantageous for scavenging nitrate-N in low depression areas. [6]

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1 NSW Agriculture (2000) Understanding soil pH. Acid Soil Action Leaflet No. 2. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf

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

3 SARE (2007) Cereal rye. Managing cover crops profitably. 3rd edn. Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

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

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

6 M Ladoni, AN Kravchenko, GP Robertson (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. *PloS ONE* 10, e0143358, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0143358

IN FOCUS

Topography mediates the influence of cover crops on soil nitrate levels

Knowledge about cover crop effects on N comes mostly from small, flat research plots, and performance of cover crops across topographically diverse agricultural land is poorly understood. This research assessed effect of a Cereal rye cover crop on potentially mineralisable N (PMN) and nitrate-N levels across a topographically diverse landscape. The study looked at conventional, low-input, and organic management strategies. The managements were implemented in 20 large undulating fields in the US starting from 2006. Data collection and analysis were conducted during three growing seasons 2011–13. Observational microplots with and without cover crops were laid within each field on three contrasting topographical positions of depression, slope and summit. Soil samples were collected four or five times during each growing season and analysed for nitrate-N and PMN. Rye cover crop had a significant 15% negative effect on nitrate-N in topographical depressions but not in slope and summit positions (Figure 1). The magnitude of the cover-crop effects on soil mineral N across topographically diverse fields was associated with the amount of cover crop growth and residue production. The results emphasise the potential environmental and economic benefits that can be generated by implementing site-specific topography-driven cover-crop management in row-crop agricultural systems. [7]

7 M Ladoni, AN Kravchenko, GP Robertson (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. *PloS ONE* 10, e0143358, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0143358

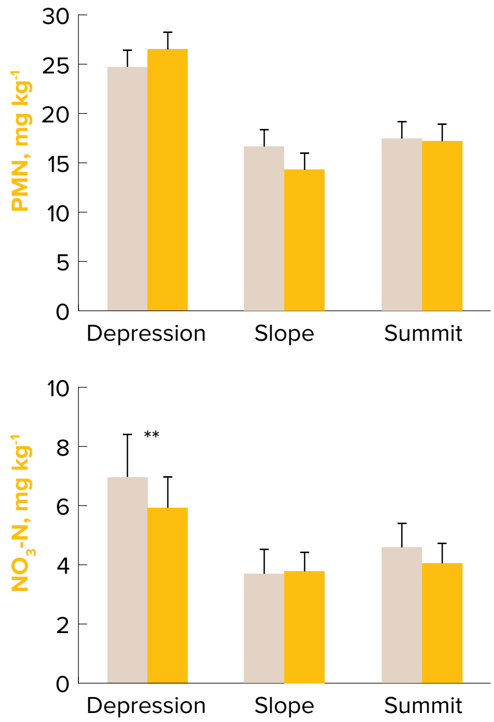

Figure 1: *Soil potential mineralisable N (PMN) and nitrate-N in bare and covered microplots of the studied topographical positions following rye cover crops. Data shown are the averages from 2011–13 results. Vertical lines are standard errors. Cases where the differences between covered and bare microplots were statistically significant are marked **P < 0.05 and *P < 0.1.* [8]

1.1.2 Soil

Soil characteristics (surface and subsurface) such as soil pH, sodicity, salinity, acidity, texture, drainage characteristics and compaction will affect choice of crop. Cereal rye is relatively inexpensive and easy to establish, and it outperforms other cover crops such as wheat on infertile, sandy or acidic soil or on poorly prepared land. [9]

Rye prefers performs well on light loams or sandy soils (Photo 1), and it will germinate even in quite dry soil. It also will grow in heavy clays and poorly drained soils, and some cultivars tolerate waterlogging. [10]

8 M Ladoni, AN Kravchenko, GP Robertson (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. *PloS ONE* 10, e0143358, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0143358

9 UVM Extension Crops & Soils Team (2011) Cereal rye. Northern Grain Growers Association, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

10 SARE (2007) Managing cover crops profitably. 3rd edn. Sustainable Agriculture Research and Education,, http://www.sare.org/publications/covercrops.htm

Photo 1: *Cereal rye growing well on sandy soils in the Mallee, 2017.*

Photo: Rob Sonogan

Rye tolerates high levels of Al in acid soils, and performs (critical concentration of $CaCl_2$-extractable Al 1.7–2.7 mg/L). [11] Cereal rye is even more tolerant of high aluminium levels than triticale, also regarded as an acid-soil-tolerant crop choice. [12]

Rye on erosion-prone soils

Rye's ability to withstand sand blast enables it to produce a soil-binding cover on land where other cereals will not grow. Under conditions where wheat, oats or barley will grow to only a few centimetres high, or they may even be blown away, rye will often grow vigorously and reach a height of at least one metre.

A further reason for using cereal rye on erosion-prone soils is that its grain and straw are the cereal least preferred by sheep. Sheep provided with more than one choice of stubble within a paddock will preferentially graze other stubbles before they will eat rye stubble.

After the crop is harvested, the tough, resilient stubble is generally left as a protective cover to reduce wind erosion of the soil and to assist colonisation by other species (Photo 2). Stubble of rye breaks down more slowly than that of other cereals, ensuring soil cover for a long period. [13]

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

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

13 Agriculture Victoria (2013) Growing cereal rye. State Government of Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Photo 2: *Wind-erosion-prone sites before and after cereal rye providing groundcover for protection.*

Source: Managing land classes for better feed utilisation

Rye is often sown on exposed sandy areas in dry regions to check sand drift. However, the weather in the spring in such regions is too dry to allow a good grain-set, and grain yields are thus highly variable. [14]

Soil pH

Key points:

- Low pH values (less than 5.5) indicate acidic soils and high pH values (more than 8.0) indicate alkaline soils.
- Soil pH between 5.5 and 8 is not usually a constraint to crop or pasture production.
- The optimum soil pH($CaCl_2$) for growth of cereal rye is ~4.5–7.5. [15]
- In South Australia, over 60% of agricultural soils are alkaline.
- Outside of the optimal soil pH range, microelement toxicity damages crops.

Soil pH is influenced by chemical reactions between soil components and water. It is affected by the various combinations of positively charged ions (of sodium, potassium, magnesium, calcium, Al, 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 2).

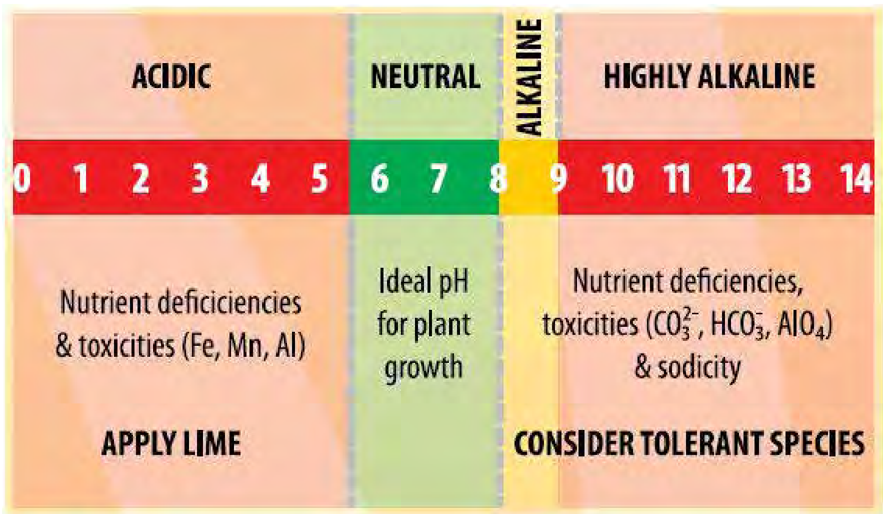

Figure 2: *Classification of soils on the basis of pH (in 1:5 soil:water), the implications for plant growth, and some management options.* [16]

Source: Soil Quality Pty Ltd

14 RL Reid (Ed.) (2013) The manual of Australian agriculture. Elsevier.

15 NSW Agriculture (2000) Understanding soil pH. Acid Soil Action Leaflet No. 2, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf

16 P Rengasamy. Soilquality.org. Soil pH—South Australia. Fact Sheets, Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/soil-ph-south-austral

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

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

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

Measurement of soil pH

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

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 <5 prefer to measure soil pH by mixing soil in a calcium chloride ($CaCl_2$) solution. This is not suitable for soils with a pH >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 >5 should be measured in water.

Managing soil pH

Alkaline soils

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

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

In high pH soils, use of alkalinity-tolerant species or varieties of crops and pasture can reduce the impact of high pH.

Acid soils

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

Soils prone to becoming acidic will need liming every few years. Seek advice on an appropriate liming regime from your local agricultural advisor. [17]

VIDEOS

WATCH: GCTV8: Liming Acids Soils.

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.

17 P Rengasamy. Soilquality.org. Soil pH—South Australia. Fact Sheets, Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/soil-ph-south-austral

Before deciding how to sample the soil, 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 placed on the information provided (Photo 3). Before starting, 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, in the right place and in the appropriate number, and are stored in such way that the required analysis is not compromised. If quantitative soil analyses (kg/ha) are required, soil bulk density must also be measured, and this requires considerable care. [18]

Photo 3: *To be meaningful, soil sampling needs to take into account spatial variation in soil condition. Differences in soil type, nutrient status and other soil properties may be exhibited within a paddock.*

Source: Soil Quality Pty Ltd

Sampling strategy

Soil properties and fertility often vary considerably, even over short distances, necessitating a sampling strategy that either integrates this variation by creating a composite sample (sampling across) or describes it by 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 by creating a composite. Examples of these are illustrated in Figure 3.

18 M Unkovich. Soil sampling for soil quality—South Australia. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia

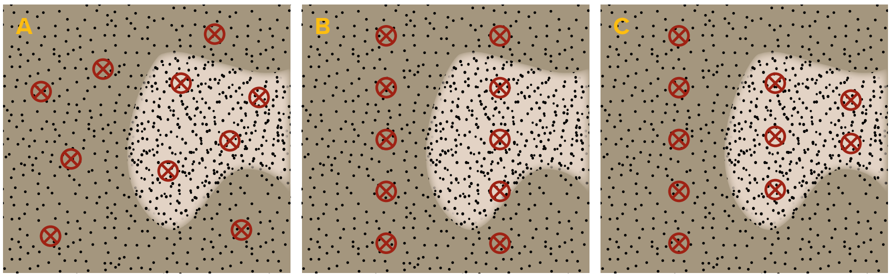

Figure 3: *Sampling strategies used to create a composite sample that integrates variation across different soil types (A & B), and a strategy to describe variation by sampling zones and analysing samples separately (C). Panel A: haphazard samples strategically located to approximate the relative representation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

Source: Soil Quality Pty Ltd

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. To avoid contamination, ensure that your sampling equipment is cleaned before starting. For greater depths, mechanical (hydraulic) samplers are usually required for most soil types. If using these for soil carbon sampling, take care not to contaminate samples with lubricating oil.

Sampling depth

Sampling for soil fertility or biological activity assessment is typically done to 10 cm depth because this is where most of the organic matter and nutrient cycling occurs. However, for mobile nutrients such as nitrate or K, deeper sampling may be required on sandier soils. Sampling to the rooting depth of a crop of interest might be useful for analysis of 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 to 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, whereas plant root material is usually included, although generally sieved out prior to analysis.

Sample handling

Samples can be stored in polyethylene bags but should generally be dried or kept cool prior to analysis. Air-drying (<40°C) is usually sufficient and storage <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, it can be reduced in size by careful quartering, ensuring no discrimination against particular particle sizes. Samples are typically put through a 2-mm sieve prior to analysis. [19]

19 M Unkovich. Soilquality.org. Soil sampling for soil quality—South Australia. Fact Sheet, Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia

1.1.4 Biological inputs

Key points:

- When evaluating a biological input for grain production, it may be useful to consider whether the input will alleviate yield constraints.
- The major yield constraints in the Southern Region are high soil density, sodicity and acidity.
- The biological inputs with the most potential to help alleviate these yield constraints are manure, compost, vermicompost, biochar and some bio-stimulants.

MORE INFORMATION

Biological inputs – Southern grain growing region

Yield constraints in the Southern Region

The Southern Region has soils with generally low fertility and many have subsoil constraints such as high soil density, salinity, sodicity, acidity and toxic levels of some elements. However, due to the diversity of soils in this region, some areas have very productive soils. Crop-production systems in the region are varied and they include many mixed-farming enterprises that have significant livestock and cropping activities.

Yield potential in the region depends on seasonal rainfall, especially in autumn and spring, with less dependence on stored soil moisture than in the Northern Region. [20]

1.2 Paddock rotation and history

The hardiest of cereals, rye can be seeded later in autumn than other cover crops and still provide considerable dry matter, an extensive soil-holding root system, significant reduction of nitrate leaching and exceptional weed suppression (Table 1). Cereal rye has multiple environmental benefits because it can be used for groundcover, reducing wind erosion, and increasing soil water retention.

Paddocks with higher fertility are preferred because most crops are sown for the dual purposes of grazing and grain. Rye is often used as a grazed cover crop undersown with medic or subterranean clover pasture on lighter soil types, to provide groundcover while the clover establishes.

Tolerance to take-all disease may make cereal rye suitable for sowing after grassy pastures. [21]

20 J Carson. Soilquality.org. Biological inputs—Southern grain-growing region. Fact Sheet, Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/biological-inputs-southern-grain-growing-region

21 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

Table 1: *Benefits and disadvantages of including cereal rye as part of crop rotations.*

Benefits of cropping cereal rye	Disadvantages of cropping cereal rye
Lower input cost than other cereal crops	Low yielding
Provides good groundcover and helps to prevent soil erosion	Difficult to get grain to markets
Taller and quicker-growing than wheat, rye can serve as a windbreak and hold moisture over winter	Lots of trash, making it difficult to seed through
Can increase soil organic carbon	Can attract armyworms
Establishes well on poor sandy soil	It has a weedy nature. Volunteer rye will usually appear for two–three years after a crop has been grown, contaminating following cereal cops
Extensive root system	It can be difficult to find a market for cereal rye grain. [25]
Requires less water than wheat crops	
Can retain up to 45 kg of excess N.	
Increases the availability of exchangeable K in the topsoil [22]	
Can attract significant numbers of beneficial insects such as lady beetles [23]	
Resistant to cereal-cyst nematodes and a poor host to root-lesion nematode (*Pratylenchus neglectus*) providing an alternative management approach for these diseases [24]	

Rye can be used to build up the fertility of sandy, infertile soils. Few other cool-season green manure crops are as productive on poor soils. Rye used as a green manure serves as a storehouse of soil nutrients for a following cash crop.

Rye can also improve water quality because the plant's extensive root system can take up excess soil N that would otherwise leach to contaminate groundwater or surface water bodies. The N taken up slowly becomes available to subsequent crops as the residues gradually decompose. Rye roots can also extract potassium and other nutrients from deep in the soil profile and bring them to the surface, where they become available to subsequent crops. Considerable fertility improvement in the topsoil can be expected when growing rye. [26]

Rye is one of the best cool-season cover crops for outcompeting weeds, especially small-seeded, light-sensitive annuals. Along with conservation tillage practices, rye provides soil protection on sloping paddocks and holds soil loss to a tolerable level. Rye can serve as an overwintering cover crop after maize, or before or after soybeans, fruits or vegetables. It should not be used before a cereal crop such as wheat or barley unless it can be killed reliably and completely; volunteer rye seed lowers the value of other grains. [27]

Cereal rye is the preferred cereal option for erosion control because it withstands adverse conditions such as cold, waterlogging, low soil pH and drought better than

22 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

23 SARE (2007) Managing cover crops profitably. 3rd edn. Sustainable Agriculture Research and Education, http://www.sare.org/publications/covercrops.htm

24 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

25 Natural Resources SA (2014) Managing land classes for better feed utilisation. Government of South Australia DEWNR, http://www.naturalresources.sa.gov.au/files/e7e04254-1bae-4763-9400-a38700980519/managing-land-classes-for-better-feed-utilisation-walsh-case-study-gen.pdf

26 H Valenzuela, J Smith (2002) Sustainable agriculture green manure crops: rye. University of Hawai'i, http://www.ctahr.hawaii.edu/oc/freepubs/pdf/GreenManureCrops/rye.pdf

27 SARE (2007) Cereal rye: Managing cover crops profitably. 3rd edn, SARE Outreach Handbook Series Book 9, University of Maryland, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

other cereals. Cereal rye has a more extensive root system in the top 30 cm than both wheat and oats. This root system increases soil stabilisation and allows the plant to explore more of the topsoil profile, increasing the plant's tolerance to dry conditions. [28]

Cereal rye's resistance and tolerance to take-all makes it a useful break crop for sowing before susceptible wheat, triticale or barley crops. (Note: the exception is the widely grown variety Bevy, which has poor resistance to take-all.) Rye can also be sown in situations where take-all is expected—following grassy pasture on soils that are unsuitable for oats. [29]

Although rye is susceptible to the same insects that attack other cereals, serious infestations are rare.

Allelopathic effects

Cereal rye produces several compounds in its plant tissues and releases root exudates that apparently inhibit germination and growth of weed seeds. These allelopathic effects, together with cereal rye's ability to smother other plants with cool-weather growth, make it an ideal choice for weed control (Photo 4).

These allelopathic compounds may also suppress germination of small-seeded vegetable crops if they are planted shortly after the incorporation of cereal rye residue. Large-seeded crops and transplants rarely are affected. There is evidence that tillering plants have lesser amounts of allelopathic compounds than seedlings. [30]

Photo 4: *High level of weed suppression exerted by a rye cover crop.*

Source: Food and Agriculture Organization of the United Nations

For more information, see Section 6: Weed control.

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

29 Wrightson Seeds (2010) Forage focus—Southern Green forage ryecorn, Wrightson Seeds, http://www.pggwrightsonseeds.com.au/assets/FTP-Uploads/Forage_Focus/Cereals/FF_Southern-Green-Forage-Ryecorn.pdf

30 V Grubinger (2010) Winter rye: A reliable cover crop. University of Vermont, https://www.uvm.edu/vtvegandberry/factsheets/winterrye.html

1.2.1 Rotation issues

Self-sown cereal rye can be a problem in subsequent cereal crops because of a high level of seed dormancy, so generally it should be sown after other cereal crops. When sown the year before a broadleaf crop such as lupins, volunteer cereal rye can be controlled with herbicides. [31]

In rotations that include a cereal, rye may replace wheat, oats, or barley. [32]

Highest yields of rye occur when it is planted on summer fallow. Growing rye repeatedly on the same land increases the chance of ergot (caused by the fungus *Claviceps purpurea*) and some other diseases. A varied crop rotation with less susceptible crops is recommended. [33]

1.2.2 Break cropping

Farmers use their soil intensively. There are pressures to grow more crop, in volume or value, to maintain profits. However, it is still important to grow cover crops. Cover (or break) crops include grasses such as rye and oats, and legumes such as cowpeas and vetch. They may be ploughed in as 'green manure' crops, or they may be mulched, slashed or sprayed ('brown-manured') then sown into.

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 2). Bare soil is easily damaged, so it is best to protect it by maintaining plant cover. [34]

The main crops used for cover cropping, such as oats, cereal rye, brown (or Indian) mustard (*B. juncea*) and forage rape, host nematodes and many of them enable rapid multiplication of nematodes. 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, these crops host and multiply nematodes, and there is little information about their impacts on other soilborne fungi. [35]

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

32 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Alternative field crops manual: Rye. Purdue University, https://hort.purdue.edu/newcrop/afcm/rye.html

33 Alberta Government (2016). Fall rye production. Agdex 117/20-1. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

34 A Senn (2007) Protect your land—use cover crops. NSW Department of Primary Industries, http://archive.dpi.nsw.gov.au/content/agriculture/horticulture/protect

35 Good Fruit and Vegetables (2014) Cover cropping practices multiplying nematodes. AgTrader.com.au, http://www.goodfruitandvegetables.com.au/story/3554224/cover-crop-practices-multiplying-nematodes/

Table 2: *Advantages and disadvantages of including cover crops in growing rotations.*

Advantages of cover cropping	Disadvantages of cover cropping
Protecting the soil: much less soil erosion and less surface crusting	**Loss of land for cash crops:** if an issue, do not grow the cover crops to maturity and grow only occasionally
Maintaining fertility: by maintaining organic matter levels in the soil, and adding N (if a legume)	**Cost of seed and sowing:** unavoidable but small. Costs usually associated with growing (e.g. watering) are generally avoidable
Weed control: a healthy cover crop keeps a paddock free of weeds	**Can become a weed**: usually not a problem in vegetable production
Disease control: by providing a break crop that helps to reduce disease, nematode and, perhaps, pest levels. For vegetable production, grasses rather than legumes tend to have most benefit	**Bulky crops**: can temporarily tie-up N and perhaps increase disease and have other effects. Trash can also get in the way
Biological tillage: less cultivation needed because cover crops loosen the soil	
Improved paddock access: in areas of medium–high rainfall, cover crops can dry out a soil profile and promote timely farm operations	

Source: NSW DPI

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) by forming structural associations with the crop root, known as arbuscular mycorrhizae (AM). Many different species of fungi can have this association with the roots of crops, and many of these 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 2000s has highlighted long-fallow disorder, where AM fungi have died out through lack of host plant roots during long fallow periods. As cropping programs restart after dry years, a yield drop is likely because of reduced levels of AM fungi and hence reduced development of AM, making it difficult for the crop to access nutrients. Long-fallow disorder is usually typified by poor crop growth. Plants appear to remain in their seedling stages for weeks and development is very slow.

Benefits of AM formation 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 species vary in their dependency on AM for growth. [36]

36 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

1.3 Fallow weed control

Paddocks with well-managed brown-manure or fallow periods significantly lower the risk of a poor crop and financial performance (Photo 5). The best form of weed control is rotation and careful selection of paddocks largely free from winter weeds, e.g. vetch that has been brown-manured.

Photo 5: *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. Knowledge of the paddock's characteristics and history, and early control of weeds, is important for good control. Information is provided below for the most common problem weeds; however, for advice on individual paddocks contact your local 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 in a long fallow) is integral to winter cropping, particularly in low-rainfall cropping areas and in regions where 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. [37]

37 GRDC (2012) Summer fallow—make summer weed control a priority. GRDC Fact Sheet January 2012, https://grdc.com.au/~/media/91deacef2dd843f6bbf9fab09bfe0d65.pdf

IN FOCUS

Summer fallow weed control and residue management impacts on winter crop yield through soil water and N accumulation in a winter-dominant low rainfall region of southern Australia.

The majority of rain used by winter grain crops in the Mallee region of Victoria falls during the cooler months of the year (April–October). However, rain falling during the summer fallow period (November–March) and stored as soil moisture contributes to grain yield. Strategies to better capture and store summer fallow rain include:

1. retention of crop residues on the soil surface to improve water infiltration and to minimise evaporation; and
2. chemical or mechanical control of summer fallow weeds to reduce transpiration and available nutrient uptake.

Despite the widespread adoption of no-till farming systems in the region, few published studies have considered the benefits of residue management during the summer fallow relative to weed control, and fewer quantify the impacts of summer fallow weeds or identify the mechanisms by which they influence subsequent crop yield. Over 3 years (2009–11), identical experiments on adjacent sand and clay soil types at Hopetoun in the southern Mallee were conducted to quantify the effects of residue management (standing, removed, or slashed) and summer fallow weed control (chemical control) compared with cultivation on accumulation of soil water and N and subsequent crop yield. The presence of residue (2.4–5.8 t/ha) had no effect on soil-water accumulation and a small negative effect on grain yield on the clay soil in 2011. Controlling summer weeds (*Heliotropium europaeum* (heliotrope) and volunteer crop species) increased soil-water accumulation (mean 45 mm) and mineral N (mean 45 kg/ha) before sowing on both soil types in two years of the experiment with significant amounts of summer fallow rain (2010 and 2011). Control of summer weeds increased grain yield of canola by 0.6 t/ha in 2010 and of wheat by 1.4 t/ha in 2011. Using the data from these experiments to parameterise the APSIM model, simulation of selected treatments with historical climate data (1958–2011) showed that an extra 40 mm of stored soil water resulted in an average additional 0.4 t/ha yield, most of which was achieved in dry growing seasons. An additional 40 kg N/ha increased yield in wetter growing seasons only (mean 0.4 t/ha on both soil types). The combination of extra water and N that was found experimentally to result from control of summer fallow weeds increased subsequent crop yield in all season types (mean 0.7 t/ha on sand, 0.9 t/ha on clay). The co-limitation of yield by water and N in the Mallee environment means that yield increases due to summer weed control (and thus returns on investment) are very reliable. [38]

38 JR Hunt, C Browne, TM McBeath, K Verburg, S Craig, AM Whitbread (2013) Summer fallow weed control and residue management impacts on winter crop yield though soil water and N accumulation in a winter-dominant, low rainfall region of southern Australia. *Crop & Pasture Science* 64, 922–934, http://www.publish.csiro.au/CP/CP13237

1.3.1 The green bridge

The green bridge provides a between-season host for insects and diseases (particularly rusts), which pose a threat to subsequent crops and can be expensive to control later in the season (Photo 6) [39].

Photo 6: *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 or summer weeds, 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 also depletes soil moisture and nutrients that would otherwise be available to following crops and can have an allelopathic effect. [40]

VIDEOS

WATCH: GCTV5: Managing summer fallow.

39 DAFWA (2016) Control of green bridge for pest and disease management. DAFWA, https://www.agric.wa.gov.au/grains/control-green-bridge-pest-and-disease-management

40 GRDC (2009) Green bridge—the essential crop management tool. GRDC Fact Sheet, http://www.grdc.com.au/uploads/documents/GRDC_GreenBridge_FS_6pp.pdf

MORE INFORMATION

GRDC: Summer fallow weed management.

VIDEOS

WATCH: Over the Fence south: Summer weed control saves moisture for winter crops.

1.3.2 Management strategies

How farming country is managed in the months or years before sowing can be more important than in-crop management in maximising water-use efficiency (WUE). Of particular impact are strategies that increase capture and storage of fallow rainfall in the soil profile 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 also have a great impact on how much plant-available water is stored at sowing. These include decisions such as crop sequence or 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 or not at critical times.

Many factors influence how much plant-available water is stored in a fallow period; however, good weed management consistently has the greatest impact. [41]

1.3.3 Benefits of stubble retention

Key points:

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

Historically, stubble has been burnt in southern Australia to create an easier passage for seeding equipment, enhance seedling establishment of crops, and improve control of some stubble-borne diseases and herbicide-resistant weeds.

However, the practice of burning stubble has declined because of concerns about soil erosion, loss of soil organic matter and air pollution. Stubble is increasingly being retained, which has several advantages for soil fertility and productivity (Photo 7).

Summer rainfall and warmer conditions promote decomposition of stubble. [42]

Photo 7: *Cereal direct-drilled into previous season's stubble in the Southern growing region.*

Photo: Rob Sonogan, 2013

41 J Cameron, A Storrie (2014) Summer fallow weed management. GRDC, https://grdc.com.au/Resources/Publications/2014/05/Summer-fallow-weed-management

42 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

Reducing erosion risk

One of the main benefits of stubble retention is reduced soil erosion. Retaining stubble decreases erosion by lowering wind speed and raindrop energy at the soil surface and decreasing runoff. Groundcover of at least 50% is required to reduce erosion. This is generally considered to be achieved by 1 t/ha of cereal stubble, 2 t/ha of lupin stubble or 3 t/ha of canola stubble. A study at Wagga Wagga, NSW, demonstrated that stubble retention reduced soil losses by almost two-thirds relative to burning paddocks. It also increased rainfall infiltration. [43]

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 mineralisation and availability of N for the subsequent crop. [44]

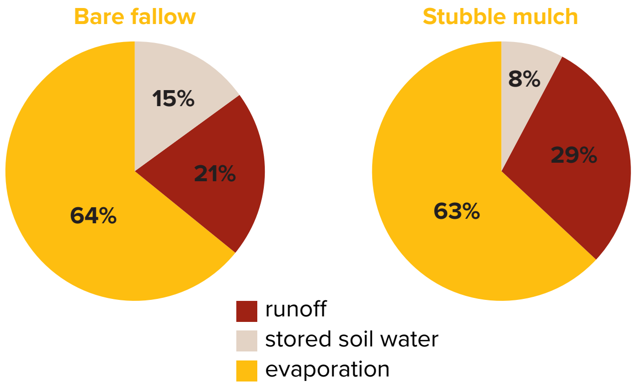

Figure 4: *Retained stubble leads to more stored soil water, mostly due to a reduction in runoff.*

Source: Felton et al. 1987, reproduced in Scott et al. 2010; from Soil Quality Pty Ltd

Increasing soil carbon

Retaining stubble increases the input of carbon to soil. Stubble is ~45% carbon by weight and represents a significant input of carbon to soil. It can take decades for retained stubble to increase the soil organic carbon (SOC). After 10 years, stubble retention generated 2 t/ha more SOC than stubble-burnt plots to a depth of 10 cm in a Red Chromosol during cropping trials with ley pasture rotations at Wagga Wagga. [45] After 25 years, inclusion of a clover pasture in the rotation in the same trial had a greater effect on SOC increases, even with tillage, than stubble retention. [46] Retaining stubble may increase SOC only where it is coupled with cultivation, but not with direct drilling. Latest findings indicate that SOC increases are extremely difficult to achieve and may be related more to annual rainfall than to any surface treatment.

VIDEOS

WATCH: Managing Stubble.

WATCH: Stubble height part 1 and part 2.

WATCH: Southern farm groups cutting through stubble issues.

43 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

44 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

45 BJ Scott, Eberbach L, J Evans, LJ Wade (2010) Stubble retention in cropping systems in Southern Australia: benefits and challenges. EH Graham Centre Monograph No. 1. NSW Industry & Investment/Charles Sturt University, https://www.csu.edu.au/__data/assets/pdf_file/0007/922723/stubble-retention.pdf

46 KY Chan, MK Conyers, GD Li, KR Helyar, G Poile, A Oates, IM Barchia (2011) Soil carbon dynamics under different cropping and pasture management in temperate Australia: Results of three long-term experiments, *Soil Research* **49**: 320–328, http://www.publish.csiro.au/sr/SR10185

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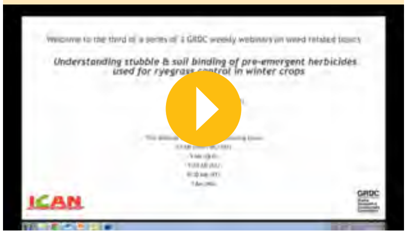
WATCH: Over the Fence south: Jim Cronin.

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



MORE INFORMATION

Developments in stubble retention.

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 between 20:1 and 41:1) are more decomposable than wheat residues (C:N between 45:1 and 178:1). Faster decomposition may improve nutrient availability for the following crop but reduce the sequestration of carbon from residues into soil. [47]

Other benefits of stubble retention

Stubble retention returns nutrients to the soil, but the amounts depend on the quality and quantity of stubble. Wheaten stubble from a high-yielding crop may return up to 25 kg available N/ha to the soil. The addition of organic matter with retained stubbles supports soil organisms and can improve soil structure, infiltration, biological activity and water-holding capacity. These benefits are greater when integrated with no-till practices. [48]

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 3).

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 for control of herbicide-resistant weeds, this should be carried out as a one-off operation. [49]

Table 3: *Estimated percentage reduction in wheat or barley stubble cover from different tillage operations; i.e. amount of residue buried by each tillage operation (reproduced from Measuring and managing stubble cover: ~~Photo~~ standards for winter cereals).*

Implement	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: Soil Quality Pty Ltd

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

1.4 Fallow chemical plant-back effects

Some herbicides have a long residual persistence. 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, such as chlorsulfuron). This is illustrated in Table 4.

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. Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop.

47 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

48 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

49 Soilquality.org. Benefits of retaining Stubble—Queensland. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld

Management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonylureas, triazines) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [50]

Table 4: *Half-life of common pre-emergent herbicides and residual persistence in broadacre trials and on-farm.* [51]
Note that it is preferable to use plant-back periods (see Table 5).

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within six weeks
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than Logran®
Diuron	90 (range 1 month–1 year, depending on rate)	High. Weed control will drop off within six weeks, depending on rate. Has had observed long-lasting 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 (more than three months) activity on broadleaf weeds such as fleabane
Simazine	60 (range 28–149)	Medium to high. One year residual in high pH soils. Has had observed long lasting (more than three months) activity on broadleaf weeds such as fleabane
Terbyne® (terbuthylazine)	6.5–139	High. Has had observed long lasting (more than six months) activity on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. Six–eight 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. Three–four months residual
Avadex® Xtra (triallate)	56–77	Medium. Three–four 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 sowthistle
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®

50 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

51 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

Conditions required for breakdown

Warm, moist soils are required for breakdown of most herbicides through the processes of microbial activity. For soil microbes to be most active, they need good moisture and an optimum soil-temperature range of 18°–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. In addition, where the soil profile is very dry, a lot of rain is needed to maintain topsoil moisture for the microbes to be active for any length of time.

Where conditions allowing breakdown of herbicide residues do not occur until just prior to sowing, crops that are sensitive to the residues potentially present on the paddock should not be planted. Rather, opt for a crop that will not be affected by the suspected residues.

If dry areas do receive rain and the temperatures become milder, substantial rain (more than the label requirement) is likely needed to wet the subsoil so that the topsoil can remain moist for a week or more. This allows the microbes to be active in the topsoil where most of the herbicide residues will be found. [52]

Soil type and pH also have an influence on the rate at which chemicals degrade.

Plant-back periods for fallow herbicides in the Southern Region

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

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

The following points are especially relevant:

- Phenoxy herbicides such as 2,4-D ester, 2,4-D amine and dicamba, require 15 mm rainfall to commence the plant-back period when applied to dry soil. There are anecdotal reports of summer-applied phenoxy herbicides staying residual in the lightest textured, low organic matter soils of the Mallee. These residues are thought to accumulate and adversely affect cereal, canola and pulse germinations. Rates of phenoxy herbicides on these soils should be monitored.
- Group B herbicide products such as Ally®, Logran® and Glean® break down more slowly as soil pH increases. Recently applied lime can increase the soil surface pH to a point where the plant-back period is significantly extended.
- Group I herbicide products such as Lontrel™, Grazon™ and Tordon™ break down very slowly under cold or dry conditions, which can significantly extend the plant-back period.

Keeping accurate records of all herbicide treatments, and planning crop sequences well in advance, can reduce the chance of damage to crops from herbicide residues (Table 5). [53]

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

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

Table 5: *Indicative plant-back intervals for a selection of fallow herbicides. For cereal rye, plant-back periods for wheat or barley are a reference point. *15 mm rainfall required to commence plant-back period; **, period may extend where soil pH is >7; #, assumes 300 mm rainfall between chemical application and sowing; NS, not specified.*

Product	Rate	Wheat	Barley	Oats	Canola	Legume pasture	Pulse crops
2,4-D 680*	0–510 mL/ha	1 day	1 day	1 day	14 days	7 days	7 days
	510–1,150 mL/ha	3 days	3 days	3 days	21 days	7 days	14 days
	1,150–1,590 mL/ha	7 days	7 days	7 days	28 days	10 days	21 days
Amicide® Advance 700*	0–500 mL/ha	1 days	1 days	1 days	14 days	7 days	7 days
	500–980 m/ha	3 days	3 days	3 days	21 days	7 days	14 days
	980–1500 mL/ha	7 days	7 days	7 days	28 days	10 days	21 days
Kamba*	200 mL/ha	1	1	1	7	7	7
	280 mL/ha	7	7	7	10	14	14
	560 mL/ha	14	14	14	14	21	21
Hammer® 400 EC		No residual effects					
Nail® 240 EC		No residual effects					
Goal®		No residual effects					
Striker®		No residual effects					
Sharpen®	26 g/ha	–	–	–	16 weeks	–	–
Lontrel™	300 mL/ha	1 week	1 week	1 week	1 week	36 weeks	36 weeks
Garlon™ 600	Various	1 week	1 week	NS	NS	NS	NS
Ally®**	Various	2 weeks	6 weeks	36 weeks	36 weeks	36 weeks	36 weeks
Logran®#	Various	–	–	–	12 months	12 months	12 months
Glean®**	Various	–	9 months	6 months	12 months	12 months	12 months
Grazon™ Extra, Grazon™ DS	Rates up to 500 mL/ha	9 months	9 months	NS	9 months	24 months	24 months
Tordon™ 75-D, Tordon™ 242	Various	2 months	2 months	NS	4 months	9 months	6 months
FallowBoss Tordon™	Up to 700 mL/ha	9 months	9 months	NS	12 months	20 months	20 months

Source: RMS Agricultural Consultants

1.4.1 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 its complexity and importance to sustainable agriculture have been appreciated only relatively recently. 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, N cycling, P solubilisation and disease suppression are usually overlooked.

Recently, the Grains Research and Development Corporation (GRDC) co-funded a five-year project to improve understanding of the potential impacts of increased herbicide use on key soil biological processes. This national project, coordinated by the NSW Department of Primary Industries with partners in Western Australia, South Australia, Victoria and Queensland, is focused 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.

Part of this project was a field survey of herbicide residues in 40 cropping soils prior to sowing and pre-emergent herbicide application in 2015 (Table 6). A literature search of herbicide impacts to soil biology was also undertaken. The relevance of the residues to soil biological processes and crop health was considered, with a focus on those herbicides most frequently detected. Recommendations were given to minimise potential impacts of herbicide residues on productivity and soil sustainability. The project will continue with further research and the development of management tools for growers to monitor and predict herbicide persistence in soils.

Table 6: *Estimated residue loads (average and maximum) of herbicide active ingredients (a.i., kg/ha) in the 0–30 cm soil profile of paddocks, by region, calculated by multiplying mass concentration (mg/kg) detected by area and average bulk density (derived from soilquality.org) for each soil layer.*

Herbicide	Average load across all sites			Maximum load detected		
	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

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 was generally considered 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

MORE INFORMATION

GRDC Update Paper: Herbicide residues in soils—are they an issue?

NSW DPI: Weed control in winter crops.

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. [54]

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

1.5 Seedbed requirements

The cereal rye paddock should be well prepared and relatively moist for good germination. [55] Good seed–soil contact is necessary for proper germination and emergence. For best results, plant rye in a firm seedbed. Preparation of soil for rye is similar to that for wheat, but is usually for a shorter period and does not include fallowing. [56]

A good seedbed is free of weeds, diseases and insects. If rye is grown on light-textured soils subject to wind erosion, pre-seeding tillage should be kept to a minimum. To aid erosion control, use implements that will preserve previous crop residue. Substitution of herbicides for cultivation and seeding without pre-seeding tillage (minimum to no-tillage) are other practical considerations. Under conditions of dry or firm soil, seeding should be done with implements that minimise soil disturbance, such as air drills with disc or narrow openers together with press-wheels, to prevent soil drying.

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

To minimise the risk of ergot infection, mowing of roadside and headland grass prior to seedset will reduce or eliminate a major source of re-infestation. [57]

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

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

Subsequent irrigations should be at cumulative evaporation minus rainfall (E – R) of 75 mm on grey soils and 50 mm on red soils.

Pre-irrigation completed by 1 April 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. [58]

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

The seedbed lays the foundations for crop establishment. However, different techniques can be used to create a seedbed (refer to Figure 5):

1. Conventional technique: ploughing in of straw, cultivation to sowing depth with a tyne/disc cultivator, conventional drilling, fertiliser spreading

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54 M Rose, L Van Zwieten, P Zhang, D Nguyen, C Scanlan, T Rose, G McGrath, T Vancov, T Cavagnaro, N Seymour, S Kimber, A Jenkins, A Claassens, I Kennedy I (2016) Herbicide residues in soils—are they an issue? GRDC Update Paper, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Herbicide-residues-in-soils-are-they-an-issue

55 UVM Extension Crops and Soils Team (2011) Cereal rye. Northern Grain Growers Association, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

56 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

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

58 Agriculture Victoria (2105) Managing winter cereals. State Government of Victoria EDJDR, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/irrigated-pastures/managing-winter-cereals

2. Mouldboard ploughing + seed-drilling: ploughing-in of straw, shallow cultivation, drilling where seed and fertiliser are placed in the soil simultaneously
3. Minimal tillage: tillage of straw by cultivator, seed drilling where seed and fertiliser are placed simultaneously in the soil–straw layer
4. Shallow tillage: shallow burial of straw at the surface, seed-drilling where seed and fertiliser are placed simultaneously in the soil–straw layer.
5. Direct drilling: seed-drilling where seed and fertiliser are placed simultaneously without prior soil tillage; straw remains on the surface.

The technique used depends on many different factors, e.g. harvest residues, equipment available, soil type, climate, labour requirement.

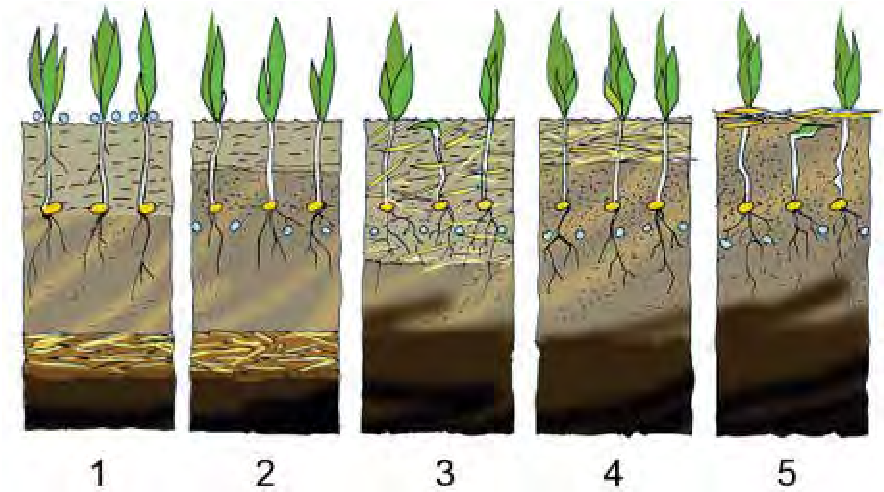

Figure 5: *Diagram demonstrating the results of different seedbed-preparation techniques. See corresponding points in text list above for description.*

Source: Vaderstad

Ploughing warms the soil and buries plant residues so that they do not obstruct sowing. However, ploughing also disrupts the soil structure and increases oxidation of organic material. Without ploughing, organic material and soil structure are retained, but the straw can cause problems with sowing and can transmit diseases. [59]

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 an indicator of soil structure.
- Increasing organic matter and decreasing traffic and stock can improve soil structure.
- Gypsum can help to alleviate problems with hard-setting or crusting.

Background

A decline in surface-soil structure generally results in crusting or hard-setting (Photo 8). A surface crust is typically <10 mm thick and when dry can normally be lifted off the loose soil below. Crusting means that the seedling must exert more energy to break through to the surface, thus weakening it. A surface crust can also form a barrier, reducing water infiltration.

Breakdown in soil structure caused by rapid wetting can lead to hard-setting. Once wet, the unstable soil structure collapses and then shrinks as it dries. This leads to

59 Väderstad (2015) Seedbed preparation. Väderstad AB, http://www.vaderstad.com/knowhow/seed-beds/seedbed-creation

a massive soil layer with little or no cracking 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. This tends to be less of a problem with cereal rye in the Mallee because it is not sown on heavy-textured soils there, but rather, on sand or loamy sands when other cereals fail.

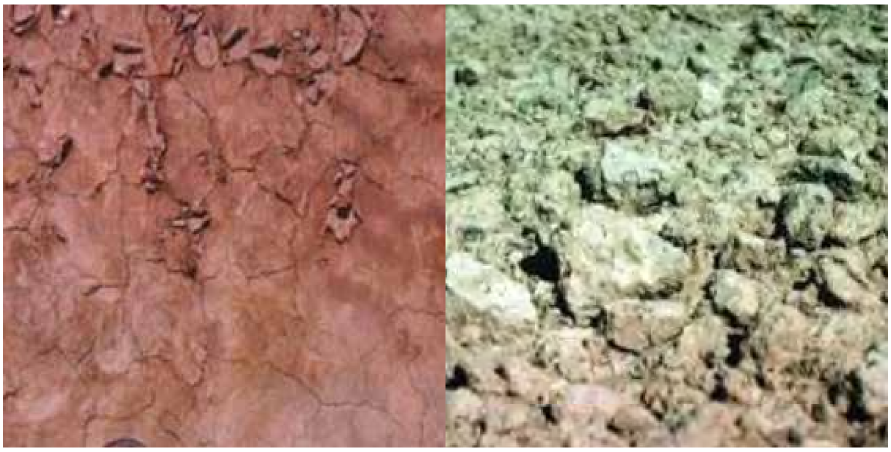

Photo 8: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium.*

Source: Soilquality.org

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, in one study, amelioration of a hard-setting grey clay was best achieved by using management practices to increase soil organic matter and reduce traffic, thereby improving soil structure. [60] Removing or reducing stock when the soil is saturated also helps to avoid compaction, smearing and 'pugging' of the soil surface.

An option for stabilising the structure of dispersive soils is the addition of gypsum. The calcium in gypsum effectively displaces sodium and causes clay particles to bind together, helping to create stable soil aggregates. A reduction in exchangeable sodium percentage and increase in ratio of calcium to magnesium may be observed. Addition of lime also adds calcium to the soil; however, this is generally used only for soils of low pH. [61]

1.6 Soil moisture

1.6.1 Dryland

Water availability is a major limiting factor for crop production in the grainbelt of Australia. Cereal rye can enhance water penetration and retention. [62]

60 Hamilton G, Fisher P, Braimbridge M, Bignell J, Sheppard J and Bowey R (2005) Managing grey clays to maximise production and stability. Department of Agriculture, Western Australia Bulletin 4666, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1033&context=bulletins

61 J Sheppard, F Hoyle.. Seedbed soil structure decline. Soil Quality Pty Ltd, www.soilquality.org.au/factsheets/seedbed-soil-structure-decline

62 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Rye. Corn Agronomy, University of Wisconsin Extension, http://corn.agronomy.wisc.edu/Crops/Rye.aspx

IN FOCUS

Soil-water extraction by dryland crops, annual pastures and lucerne in south-eastern Australia

The extraction of soil water by dryland crops and pastures in south-eastern Australia was examined in 3 studies. The first was a review of 13 published measurements of soil-water use under wheat at several locations in southern New South Wales. Of these, eight showed that crops extracted significantly more water when they were grown with an increased nitrogen supply or after a break crop. The mean additional soil-water extraction in response to extra N was 11 m, and after break crops was 31 mm.

The second study showed how good management can change crop yields and prevent the unnecessary loss of water. Researchers used the SIMTAG model to simulate growth and water use by wheat at Wagga Wagga. The model was set up to simulate two typical situations: crops that produced average district yields; and crops that might produce greater yields with good management. When simulated over 50 years of weather data, the combined water loss as drainage and run-off was predicted to be 67 mm/year for poorly managed crops and 37 mm for well-managed crops. Water outflow was concentrated in 70% of years for the poorly managed crops and 56% for the well-managed crops. In those years the mean losses were estimated to be 95 mm and 66 mm, respectively.

The third study reported on soil water measured twice each year during a phased pasture–crop sequence over 6.5 years at Junee. Mean water content of the top 2.0 m of soil under a lucerne pasture averaged 211 mm less than under a subterranean clover-based annual pasture and 101 mm less than under well-managed crops.

Collectively, these results suggest that lucerne pastures and improved crop management can result in greater use of rainfall than the other farming systems, which were based on growing annual pastures, and using fallow, and poor management techniques for growing crops. The tactical use of lucerne-based pastures in sequence with well-managed crops can help the dewatering of the soil and reduce or eliminate the risk of groundwater recharge. [63]

Monitoring soil moisture in dryland areas

Grain growers are under pressure to increase production across the seasons; adding to the complexity of this demand is the likelihood that, if the climate becomes more variable, rainfall may decrease or its distribution change. Even now, current cropping systems may not be maximising Water Use Efficiency, if growers are relying on subjective assessments. Few are able to monitor the amount of water available to the crop, and hence cannot supply the crop with the appropriate amount of inputs to maximise yield.

One tool that helps farmers improve Water Use Efficiency is the soil-moisture probe, but few farmers in the dryland cropping industry use it. To change that, Victoria's Department of Environment and Primary Industries will provide live deep-soil-moisture data to help dryland croppers, farmers, and advisers and managers validate the technology, as well as conducting training to interpret the data for crop

63 JF Angus, RR Gault, MB Peoples, M Stapper, AF Van Herwaarden (2001) Soil water extraction by dryland crops, annual pastures, and lucerne in south-eastern Australia. Crop and Pasture Science, 52 (2), 183–192.

decision-making. [64] Communication will include monthly broadcasts of 'The Break', soil-moisture products; and the government will piloting new formats to expand reach and impact.

This project will assist people in the grain sector to lift production and improve grain quality to meet the demand of the growing Asian consumer market (via the government's Food to Asia plan). Increasing targeted inputs and improving crop management will be accomplished by educating industry to understand soil and water interactions and critical crop growth stages, as well as factoring in seasonal forecasts.

Access to this data enables growers and advisers to:

- Measure moisture at one representative point in the paddock for a farm in the region.
- Use live soil-moisture data that is collected from a representative site for a particular rainfall region and soil type.
- Monitor local weather (rain, wind and temperature and humidity) and download historical data from an archive list for farm management records.
- Increase production and efficiencies.
- Help farmers to adapt to climate variability.
- Make informed decisions such as minimising input in low-decile years with a low soil-moisture base and maximising yield potential in more favourable conditions, based on current soil-moisture levels and incorporating knowledge from seasonal forecasts.
- Determine if measurements obtained through the life of the project could be relevant at whole-farm or even district level.

MORE INFORMATION

Soil moisture monitoring in dryland cropping areas

1.6.2 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–soil contact (Photos 9 and 10).

Research at five sites in Queensland and northern New South Wales has shown that one-time tillage with chisel or offset disc in a long-term, no-tillage system helped to control winter weeds and slightly improved grain yields and profitability, while retaining many of the soil quality benefits of no-till farming systems. Tillage reduced soil moisture at most sites; however, this decrease in soil moisture did not adversely affect productivity. This could be due to good rainfall received after tillage and prior to seeding and during the crop of that year. Rainfall between the tillage and sowing or immediately after sowing is necessary to replenish soil water lost from the seed zone. This suggests the importance of timing of tillage and of considering the seasonal forecast. Future research will determine the best timing for strategic tillage in no-till systems. [65] Note that these results are from one season and research is ongoing, so any impacts are likely to vary with subsequent seasonal conditions.

64 Agriculture Victoria (2016) Soil moisture monitoring in dryland cropping areas. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/soil-moisture-monitoring-in-dryland-cropping-areas

65 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, February 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Tillage-impact-in-long-term-no-till

Photo 9: *The impact of tillage varies with the tillage implement used: inversion tillage using a mouldboard plough, as pictured, results in greater impacts than using a chisel or disc plough.*

Source: GRDC

Photo 10: *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 awnless barnyard grass in fallow.*

Source: GRDC

However, tillage can also increase 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 hectares worldwide in 1999 to 111 million hectares in 2009. One downside of this trend is increased use of herbicides for weed suppression. [66]

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 cereal grains, no-till establishment is an effective option that allows maintenance of the no-till system. Conventional seedbeds are prepared by ploughing, discing and harrowing the soil prior to seeding. Seeding depth depends upon the species being sown. [67]

VIDEOS

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

WATCH: Over the Fence South: Andrew Simpson – Strategic tillage.

66 MR Ryan, SB Mirsky, DA Mortensen, JR Teasdale, WS Curran (2011) Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. *Weed Science* 59, 238–246, http://www.bioone.org/doi/abs/10.1614/WS-D-10-00110.1

67 WS Curran, DD Lingenfelter, L Garling. Cover crops for conservation tillage systems. Penn State Extension, http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/cover-crops-for-conservation-tillage-systems

IN FOCUS

Tillage, microbial biomass and soil biological fertility

In the mid-1990s, no-tillage farmers called for an experiment to test anecdotal reports that low-disturbance tillage increased total organic carbon (TOC) in soil.

A seven-year experiment was conducted in the central wheatbelt of Western Australia on a property with deep sandy soil that was using a lupin–wheat rotation. The experiment compared the effect of three tillage types on TOC, light-fraction organic carbon (LFC), soil microorganisms and crop yields:

1. No-tillage—no soil disturbance other than seeding
2. Conservation tillage—a single pass before seeding with 13-cm-wide tynes to a depth of ~7.5 cm
3. Rotary tillage—a single intense cultivation before seeding to a depth of 8 cm, using a rotary hoe.

Total organic carbon

The TOC is a measure of all carbon contained within soil organic matter. Low levels can indicate problems with unstable soil structure, low cation exchange capacity and nutrient turnover (see Soil Quality Fact Sheet: Total organic carbon).

After seven years, TOC had increased by 4.4 t/ha under no-tillage and by 2.6 t/ha under conservation tillage (Figure 6), but had decreased by 0.5 t/ha under rotary tillage.

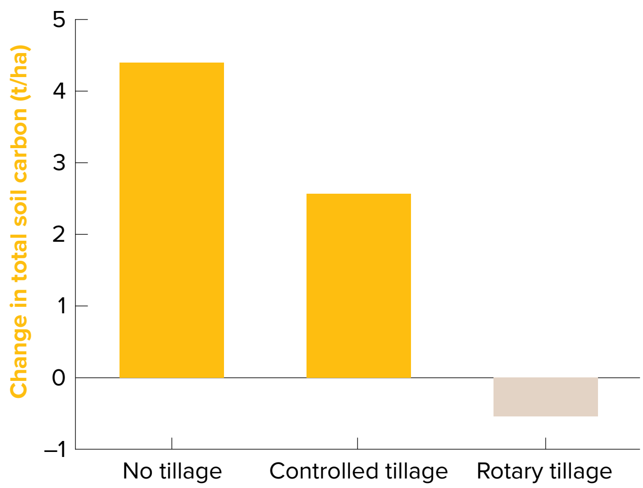

Figure 6: *Change in total soil carbon content at 0–10 cm soil depth from 1998 to 2004 in crops under three tillage regimes. No-tillage and conventional tillage treatments were not significantly different from each other; rotary tillage was significantly different from both (at P = 0.05).*

Source: Soilquality.org

Light-fraction organic carbon

The LFC consists of more recent, readily decomposable inputs of organic matter. LFC responds more quickly to management than TOC and better reflects changes in soil microbiology. The LFC decreased as tillage became more intensive.

By the end of the experiment, LFC in the top 10 cm was 0.83 t/ha under no-tillage, 0.73 t/ha under conservation tillage and 0.46 t/ha under rotary tillage.

This may indicate that less intensively tilled soils are more biologically active and have higher potential for nutrient turnover, and that TOC may increase further in the future.

On the other hand, the losses with rotary tillage of both TOC and LFC could lead to degradation of soil structure and ultimately to a decline in productivity.

Soil microorganisms

Microbial biomass carbon is a measure of carbon in the soil microorganisms (see Soil Quality Fact Sheet: Microbial biomass). Microbial biomass carbon in 0–5 cm soil decreased under rotary tillage compared with no-tillage and conservation tillage (Figure 7).

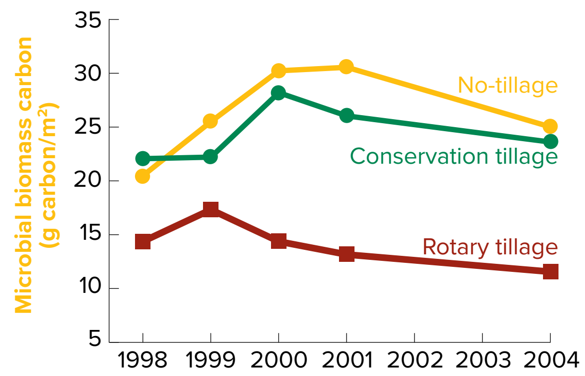

Figure 7: *Microbial biomass carbon at 0–5 cm depth of cropped soil under three tillage regimes.*

Source: Soilquality.org

Microbial biomass nitrogen was also higher under no-tillage and conservation tillage than under rotary tillage. By the end of the experiment, microbial biomass nitrogen under no-tillage and conservation tillage was 31% higher than under rotary tillage.

Tillage also decreased microbial activity in soil. The activity of the microbial enzyme cellulase at 0–5 cm soil depth was higher under no-tillage and conservation tillage than rotary tillage (Figure 8).

This indicates that less intensive cultivation may favour sustained microbial function in soil.

MORE INFORMATION

GRDC Tips and Tactics: Strategic Tillage

VIDEOS

WATCH: Adoption of NoTill SA Mallee.

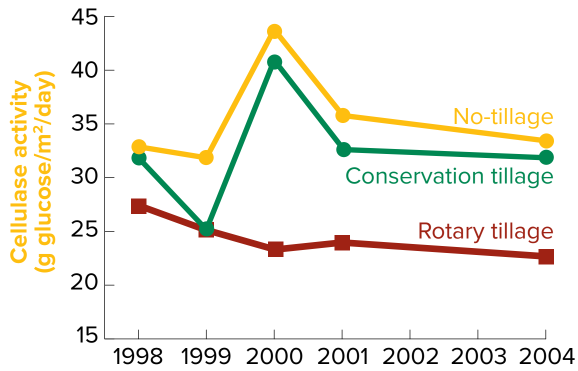

Figure 8: *Activity of the microbial enzyme cellulase at 0–5 cm depth of cropped soil under three tillage regimes.*

Source: Soilquality.org

Crop yields

Tillage practice did not affect crop yields except in one year of the trial, 2003, when lupin grain yields were higher under no-tillage (2 t/ha) and conservation tillage (1.9 t/ha) than under rotary tillage (1.6 t/ha).

Although tillage did not affect wheat grain yield, it did affect the incidence of Rhizoctonia bare patch (caused by *Rhizoctonia solani*; see Soil Quality Fact Sheet: Rhizoctonia). Wheat plants grown under both no-tillage and conventional tillage were more visibly affected by Rhizoctonia bare patch than those grown under rotary tillage.

Although overall results for no-tillage and conservation tillage were similar, they may diverge in the longer term. [68]

1.6.3 Irrigation

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

The keys to maximising irrigation efficiency are uniformity and timing. Although the producer can control the quantity and timing of water supply, the irrigation system determines uniformity. Deciding on the most suitable irrigation system for your operation requires 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 though evaporation and runoff, and from water (and nutrients) sinking deep below the root-zone.

Irrigation management requires careful consideration and vigilance.

Benefits of irrigation:

- Increased production of pastures and crops.

68 M Roper, J Carson, D Murphy. Tillage, Microbial biomass and soil biological fertility. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/tillage-microbial-biomass-and-soil-biological-fertility

- More flexibility in systems/operations with the ability to access water when needed to achieve good plant growth and thus higher yields and to meet market/seasonal demands, especially if rainfall events do not occur.
- Higher quality crops and pastures—water stress can reduce the quality of farm produce.
- Lengthening of the growing season (or in starting the season earlier).
- Insurance against seasonal variability and drought.
- Higher stocking rates of animals and tighter grazing management due to reliability of pasture supply throughout the season.
- Maximising benefits of fertiliser applications—fertilisers need to be 'watered into' the soil to facilitate plant growth.
- Use of areas that would otherwise be less productive—irrigation can allow farmers to open up land that would otherwise be too dry to grow pasture or crops, enhancing carrying capacity or feed conservation.
- Ability to take advantage of market incentives for unseasonal production.
- Less reliance on supplementary feeding (grain, hay) in grazing operations due to the more consistent supply and quality of pastures grown under irrigation.
- Improved capital value of the property—irrigated land has potential to support higher crop, pasture and animal production, so is considered more valuable. The value is also related to the water-licensing agreements.
- Cost saving and greater returns—cost benefits from the more effective use of fertilisers and financial benefits of more effective agricultural productivity (both quality and quantity) and out-of-season production are likely. [69]
- Effective in increasing shoot zinc (Zn) content and Zn efficiency of cereal cultivars—it has been suggested that plants become more sensitive to Zn deficiency under rainfed conditions. [70]

However, cereal rye may not respond to irrigation as well as other cereal crops. In one study, cereal varieties accumulated 16–20 t/ha of dry matter by the end of sampling in late September, whereas cereal rye yielded only 14 t/ha. [71]

IN FOCUS

Dry matter accumulation and changes in forage quality during primary growth and three regrowths of irrigated winter cereals

Selected cultivars of oats (3), barley (2), wheat (3), cereal rye (1) and triticale (3) were grown under irrigation at Trangie, NSW, in 1978 and 1980. Dry matter (DM) accumulation and changes in moisture, nitrogen (N) and phosphorus (P) content and DM digestibility of forage were monitored at intervals of ~21 days during uninterrupted primary growth (June–September 1980). In a split-plot design with three cutting intensities, the crops were cut at 80 days, 80 and 122 days, and 80, 122 and 164 days after sowing. Regrowth was sampled on two or three occasions to determine DM yield and quality. Most cultivars accumulated 16–20 t DM/ha by the end of sampling in late September; cereal rye yielded only 14 t/ha. Early-maturing Minhaffer oats produced the highest yield when uncut but regrew poorly after cutting. Under a 42-day cutting interval oats and barley yielded

69 Agriculture Victoria. About irrigation. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/irrigation/about-irrigation

70 H Ekiz, SA Bagci, AS Kiral, S Eker, I Gültekin, A Alkan, I Cakmak (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, 2245–2256.

71 DK Muldoon (1986) Dry matter accumulation and changes in forage quality during primary growth and three regrowths of irrigated winter cereals. *Australian Journal of Experimental Agriculture* 26, 87–98, http://www.publish.csiro.au/an/EA9860087

12–13 t/ha, winter wheat yielded 10–11 t/ha and triticale yielded 10–12 t/ha. Nitrogen and P content of all forages decreased linearly during primary growth. Oats and wheat had similar digestibility, which began to decrease rapidly 40–50 days before head emergence (mid-August). Early-maturing barley and triticale cultivars had lower digestibility than oats. Regular cutting maintained the N content and digestibility of all cultivars above 2.7% and 72%, respectively. DM accumulation was described by mathematical equations that allowed cultivars to be compared under different cutting regimes. Equations also allowed DM and digestible DM yields from different systems of cutting to be predicted for irrigated cereals in western NSW. [72]

MORE INFORMATION

Agriculture Victoria: About irrigation

GRDC Update Paper: The Future of irrigation, what's in store

The future of irrigation

Climate change is likely to lead to reductions in rainfall in south-eastern Australia. These reductions in rainfall will be amplified such that proportional reductions in runoff are likely to be two–four times larger. That is, a 10% rainfall reduction will lead to a 20–40% reduction in runoff. The runoff reductions will be larger in drier catchments, making the water supply systems with drier source catchments more vulnerable. The experience of the Millennium Drought has shown that reductions in runoff under persistent climate change (~10-year drought) are larger than reductions that occur for short droughts with similar rainfall reductions in many catchments. [73]

1.7 Yield and targets

Australia's climate—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.

The average yield of cereal rye in Victoria is low and quite variable: 0.4–1.8 tonnes per hectare. Spring rainfall has a major influence on yield in the Mallee because the lighter soils have a low water-holding capacity; low spring rainfall will lead to lower yields. Another factor in the low yields is that, unlike other cereals, rye must be cross-pollinated. In hot weather, much of the pollen dries out before it can fertilise neighbouring plants; the result is that grain does not set properly. A third factor in the low yields is that most varieties of rye require a relatively long period for grain formation; this means that rye grain can often be small and shrivelled. [74]

In cereal rye, 53–58% of total grain yield is produced by lateral shoots, depending on the cultivar and the growing conditions. [75]

Cereal rye is adapted to all soils; however, its major fit is on the lighter acid soils where yields are usually 70–100% those of wheat and triticale when sown between May and June.

On traditional wheat soils, yields of cereal rye are ~50–70% of wheat yields. When sown late (in July), and in dry springs, yields are often <50% those of comparable wheat. Although it heads early, its longer grain-filling period and later maturity limit its performance in the western areas of the grainbelt. [76]

72 DK Muldoon (1986) Dry matter accumulation and changes in forage quality during primary growth and three regrowths of irrigated winter cereals. *Australian Journal of Experimental Agriculture* 26, 87–98, http://www.publish.csiro.au/an/EA9860087

73 A Western, M Saft M, M Peel (2016): The future of irrigation—what's in store? GRDC Update Papers https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/The-future-of-irrigation-whats-in-store

74 Agriculture Victoria (2013) Growing cereal rye. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

75 K Hakala, K Pahkala (2003) Comparison of central and northern European winter rye cultivars grown at high latitudes. *The Journal of Agricultural Science*, 141, 169–178.

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

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

- Do a simple calculation to see how much water is needed to achieve this yield. [77]
- Know how much soil water is available (treat this water like money in the bank).
- Think about how much risk your farm can carry.
- Consider how this crop fits into your cropping plan, will the longer term benefits to the system outweigh any short-term losses?
- Avoiding a failed crop saves money now and saves stored water for future crops. [78]

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 the best asset for estimating yield at early stages of growth. As crops near maturity, it becomes easier to estimate yield with greater accuracy.

Estimation methods

Many methods are available for farmers and others to estimate yield of various crops. The method presented here 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 a measuring rod or tape, measure out an area 1 m^2 and count the number of heads/pods.
2. Do this five times to get an average for the crop: no. of heads per m^2 (e.g. 200).
3. Count the number of grains in at least 20 heads, and calculate the average: no. of grains per head (e.g. 24).
4. Determine the 100-grain weight for the crop (in grams) by referring to table 1 in: Estimating crop yields—a brief guide; or in this case for cereal rye, assume 40,000 seeds per kg, from Matthews *et al.* (2016, table 14, p. 27). [79] Then (1000/40,000) × 100 = 2.5 g.
5. No. of grains per m^2 = no. of heads per m^2 × no. of grains per head; e.g. 200 × 24 = 4800.
6. Yield per m^2 (g) = (no. of grains per m^2/100) × 100-grain weight; e.g. 4800/100 × 2.5 = 120 g.
7. Yield (t/ha) = numeric value of yield per m^2/100; e.g. 120/100 = 1.2 t/ha.

Accuracy of yield estimates depends upon an adequate number of counts being taken to get a representative average of the paddock. The yield estimate determined will be a guide only.

This type of yield estimation 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% loss should be included in your final calculations. [80]

77 J Whish (2013) Sorghum yield risk vs starting soil moisture. GRDC Update Papers, August 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Sorghum-yield-risk-vs-starting-soil-moisture

78 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

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

80 Agriculture Victoria. Estimating crop yields; a brief guide. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/estimating-crop-yields-a-brief-guide

Yield Prophet®

Scientists at the Agricultural Production Systems Research Unit (APRSU) 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 had valuable impacts in terms of assisting farmers to manage climate variability at a paddock level.

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

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

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.

The NSW Seasonal Conditions Reports are issued each month and contain information on rainfall, water storages, crops, livestock and other issues. They are available to landholders to help them make informed decisions on how they manage operations, and prepare for seasonal conditions and drought.

MORE INFORMATION

GRDC Update Paper: Managing data on the modern farm

BoM: Australia Bureau of Meteorology climate outlooks

GRDC: Climate kelpie

For Victorian growers, the Victorian State Government publishes the Monthly Water Report including updates from the Bureau of Meteorology on local rainfall forecasts and seasonal climate outlook.

Mobile applications (apps) are providing tools for ground-truthing of 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. [81]

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

Download from the Apple iTunes store 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 with previous seasons, based on heat sum?
- Is there any reason why my crop is not doing as well as usual because of below-average rainfall or radiation?
- Based on 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. [82]

Climate analogues

Climate Change in Australia provides projections for Australia's natural resource management regions. Its Climate analogues tool matches the proposed future climate of a location of interest with the current climate experienced in another location by using annual average rainfall and maximum temperature.

For example, based on plausible assumptions about changes in temperature and rainfall, the future climate of Melbourne will be like the current climate of a location identified by this tool.

This approach was used to generate the analogue cases presented as examples in each of eight Cluster Reports. These reports are intended to provide regional detail for planners and decision makers. The results should capture sites of broadly similar annual maximum temperature and water balance. [83]

81 R Heath (2013) Managing data on the modern farm. GRDC Update Papers, February 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Managing-data-on-the-modern-farm

82 Australian CliMate—Climate tools for decision makers. Managing Climate Variability R & D Program, http://www.australianclimate.net.au

83 Climate Change in Australia. Climate analogues. Australian Department of the Environment, Bureau of Meteorology, http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/

1.7.2 Fallow moisture

For a growing crop, there are 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. 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 Southern Oscillation Index can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when it is needed. [84]

HowWet?

HowWet? is a program developed by APSRU that uses records from a nearby weather station to estimate how much plant-available water has accumulated in the soil and the amount of organic N that has been converted to 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?* provides a comparison with previous seasons.

This information aids 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 the soil type on my farm 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 for 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 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. [85]

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 comprises:

84 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

85 Australian CliMate—How Wet/N. Managing Climate Variability R & D Program, http://www.australianclimate.net.au/About/HowWetN

- 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; and
- the crop's ability to convert biomass into grain.

Water Use Efficiency can be considered at several levels:

- Fallow efficiency (%) is the efficiency with which rainfall (mm) during a fallow period is stored for use by the following crop. Calculated as: fallow efficiency = (change in plant-available water during fallow × 100)/fallow rainfall.
- Crop WUE (kg/ha/mm) is the efficiency with which an individual crop converts water transpired (or used) (mm) to grain (kg/ha). Calculated as: crop WUE = grain yield/(crop water supply – soil evaporation).
- Systems WUE (kg/mm) is the efficiency with which rainfall is converted to grain over multiple crop and fallow phases. Calculated as: systems WUE = total grain yield/total rainfall.

Strategies to increase yield

In environments where yield is limited by water availability, there are four ways to increase yield: [86]

1. Increase the amount of water available to a crop through practices such as good control of summer weeds, stubble retention, long fallow and early sowing to increase rooting depth.
2. Increase the proportion of water that is transpired by crops rather than lost to evaporation or weeds. This can be achieved by early sowing, early N application, vigorous crops and varieties, narrow row spacing, high plant densities, stubble retention and good weed management.
3. Increase the efficiency with which crops exchange water for carbon dioxide to grow dry matter (i.e. transpiration efficiency) through early sowing, good nutrition and use of varieties with high transpiration efficiency.
4. Increase the total proportion of dry matter that is grain (i.e. improve the harvest index) by using early-flowering varieties and varieties with high harvest index, delayed N application, wider row spacing, low plant densities and disease minimisation practices.

The last three of these all improve WUE. [87]

The French–Schultz approach

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

In this model, potential crop yield is estimated as:

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

In the equation, 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.

86 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

87 J Hunt, R Brill (2012) Strategies for improving Water Use Efficiency in western regions through increasing harvest index. GRDC Update Papers, April 2012, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Strategies-for-improving-wateruse-efficiency-in-western-regions-through-increasing-harvest-index

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, and 46% achieved 13–17 kg/ha/mm.

A practical WUE equation for farmers to use developed by James Hunt (CSIRO) is: WUE = (yield × 1000)/available rainfall, where available rainfall = (25% Nov.–March rainfall) + (growing season rainfall) – 60 mm evaporation.

Agronomist's view

The French–Schultz model has been useful in providing growers with performance benchmarks. Where yields fall well below these benchmarks, it may indicate a problem 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 simply be due to seasonal rainfall distribution patterns, which are beyond the grower's control. [88]

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

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

Understanding how these 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 in 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 levels (i.e. $/ha.mm). [89]

1.7.4 Nitrogen-use efficiency

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 efficiency of conversion of fertiliser into grain 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. [90]

Improving NUE

Improving N-use efficiency (NUE) begins with identifying and measuring meaningful NUE indices, and comparing them with known benchmarks and contrasting N-management tactics. Some useful NUE indices are:

- agronomic efficiency of applied N (kg yield increase per kg N applied)
- N transfer efficiency (kg N in grain/kg total crop-available N)

MORE INFORMATION

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

NSW DPI Agnote: Making the most of available water in wheat production.

VIDEOS

WATCH: GCTV12: Water Use Efficiency Initiative.

WATCH: GCTV10: Grazing stubbles and Water Use Efficiency.

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

89 Rodriguez (2008) Farming systems design and Water Use Efficiency (WUE). Challenging the French & Schultz WUE model. GRDC Update Papers, 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

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

- economic agronomic efficiency (value of yield increase with applied N/cost of N fertiliser applied).

Potential causes of inefficiency can be grouped into six general categories:

- supply greater than demand
- inefficient N uptake
- applied but temporarily unavailable to the growing crop (immobilisation)
- applied or mineralised but lost to soil through leaching, volatilisation, denitrification
- available but not taken up because of positional or timing problems, or root restriction
- taken up but not transferred to grain.

Identification of the most likely category is useful in directing more targeted measurement and helping to identify possible strategies for improvement.

Because of seasonal effects, improvement of NUE is an iterative process. Therefore, consistency in investigation strategy and good record keeping are essential. [91]

Optimising N fertiliser use

Nitrogen fertilisers are a significant expense for broadacre farmers. Optimising use of fertiliser inputs is therefore desirable. There are three main stores of nitrogen with the potential to supply N to crops: stable soil organic matter N, rotational (plant residue) N, and soil mineral N (ammonium and nitrate). To optimise the ability of plants to use soil N, growers should first be aware of how much of each source there is, and soil testing is the best method of measuring these N sources. [92]

IN FOCUS

Environment and genotype influence on grain protein concentration of wheat and rye

Protein is a primary quality component of cereal grains. Cultivar and agronomic trials were conducted in Canada to determine the influence of genotype and environment on wheat and rye grain protein concentration and NUE for grain protein production. Minimum protein concentration of 95.4 g protein/kg dry grain was expressed when cultivars were produced under high productivity conditions on soils with low total plant-available N. Maximum protein concentration at high levels of N varied from 130 to 231 and 107 to 177 g protein/kg dry grain for winter wheat and rye, respectively. At low levels of total available N, the NUE for grain protein production approached 80%. The NUE for grain protein production dropped off rapidly for subsequent increments of N fertiliser. These observations indicate that management systems designed to produce cereals with high grain protein concentrations will have a very low NUE for grain and grain protein production. [93]

MORE INFORMATION

GRDC Update Paper: The fundamentals of increasing nitrogen use efficiency

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

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

93 DB Fowler, J Brydon, BA Darroch, MH Entz, AM Johnston (1990) Environment and genotype influence on grain protein concentration of wheat and rye. *Agronomy Journal* 82, 655–664.

1.7.5 Double crop options

Cool-season annual forages such as cereal rye are well suited to use as double-cropped forage. [94]

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 cereal grasses such as oats, cereal rye, triticale 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 because 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 outweigh the years in which failure occurs. [95]

For spring forage, the winter cereals rye, triticale and wheat tend to be the best choices. Rye is the best choice for early spring pasture and produces much growth before being terminated for timely planting of a row crop. Some rye varieties also provide enough autumn growth for some light grazing if planted early enough. Rye also may be the most reliable crop when planted under stressful conditions. [96]

1.8 Disease status of paddock

Although cereal rye is susceptible to fewer diseases than other cereals [97], it important to know the disease status of a paddock before planting.

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 below) levels in a prior cereal crop, paying attention to basal browning, and/or having soil samples analysed at a testing laboratory. Use of a Predicta B test can be beneficial (see below).

1.8.1 Cropping history effects

The main cropping history effects are based on the amount of nutrients available in a paddock. However, 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. 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;

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94 ME Drewnoski, DD Redfearn (2015) Annual cool-season forages for late-fall or early-spring double crop. NebGuide, University of Nebraska, http://extensionpublications.unl.edu/assets/pdf/g2262.pdf

95 ME Drewnoski, DD Redfear (2015) Annual cool-season forages for late-fall or early-spring double crop. NebGuide, University of Nebraska, http://extensionpublications.unl.edu/assets/pdf/g2262.pdf

96 Cropwatch (2012) Considerations for late summer planted forage crops. University of Nebraska, http://cropwatch.unl.edu/considerations-late-summer-planted-forage-crops

97 SARE (2007) Cereal rye: Managing cover crops profitably. 3rd edn. SARE Handbook, Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

the use of high-quality, fungicide-treated seed; planting within the planting window; variety selection; and in-crop fungicide treatments. [98]

Paddock histories likely to result in high risk of disease (e.g. Rhizoctonia) include:

- durum wheat in the past 1–3 years
- winter cereal or a high grass burden from last season—crown rot fungus survives in winter cereal residues, dense stubble cover or where dry conditions have made residue decomposition slow
- break crops, which can influence crown rot in cereals by manipulating the amount of 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 [99]
- varieties grown in previous year (Photo 11). [100]

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

Source: DAFWA

1.8.2 Soil testing for disease

In addition to visual symptoms, the DNA-based soil test PreDicta B can be used to assess 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 wheat varieties, and for assessing the risk after a non-cereal crop.

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 is a DNA-based soil testing service that identifies which soilborne pathogens pose a significant risk to broadacre crops prior to seeding (Photo 12).

98 M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers, September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54 t/a9ft5hf

99 GRDC (2009) Crown rot in cereals. GRDC Fact Sheet May 2009, https://www.grdc.com.au/~/media/AF642FA0A889465089D2B6C59E5CA22E.pdf

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

Photo 12: *Taking a sample for a PreDicta B test for crown rot.*

Source: GRDC

PreDicta B includes tests for:

- take-all (*Gaeumannomyces graminis var. tritici* and *G. graminis var. avenae*)
- Rhizoctonia barepatch (*Rhizoctonia solani AG8*)
- crown rot (*Fusarium pseudograminearum and F. culmorum*)
- blackspot of filed peas (*Mycosphaerella pinodes, Phoma medicaginis var. pinodella* and *Phoma koolunga*).

Accessing PreDicta B testing service

Growers can access PreDicta B diagnostic testing services through an agronomist accredited by the South Australian Research and Development Institute (SARDI). They will interpret the results and give you advice on management options to reduce your risk of yield loss.

SARDI processes PreDicta B samples weekly between February and mid-May (prior to crops being sown) every year, to assist growers with their cropping programs.

PreDicta B is not intended for in-crop diagnosis. See SARDI's Crop diagnostic webpage for other services.

For more information, see Section 9: Diseases.

1.8.3 Nematode status of paddock

Pratylenchus thornei and *P. neglectus* (both RLN) are migratory root endoparasites that are widely distributed in the wheat-growing regions of Australia and can reduce grain yield by up to 50% in many current wheat varieties (Photo 13). *Pratylenchus neglectus* and *Pratylenchus thornei* are the main RLN species causing yield loss in the southern agricultural region of Australia, and they can often occur together. [101]

At least 20% of cropping paddocks in south-eastern Australia have populations of RLNs high enough to reduce yield. [102]

101 QDAF (2010) Test your farm for nematodes. Queensland Department of Agriculture and Fisheries, July 2010, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematodes/test-your-farm-for-nematodes

102 Agriculture Victoria (2013) Cereal root diseases. State Government of Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

Photo 13: *Paddock showing patches caused by root-lesion nematodes.*

Source: DAFWA

Rye is relatively resistant, and can help to reduce root-knot nematodes (*Meloidogyne* spp.) and other harmful nematodes. [103]

Nematode testing of soil

PreDicta B includes tests for:

- cereal cyst nematode (*Heterodera avenae*).
- RLN (*Pratylenchus neglectus and P. thornei*).
- stem nematode (*Ditylenchus dipsaci*).

Effects of cropping history on nematode status

- Well-managed rotations are vital. Avoid consecutive host crops to limit populations.
- Choose wheat varieties with high tolerance ratings to maximise yields in fields where 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.

MORE INFORMATION

GRDC Tips and Tactics: Root-lesion nematode Southern Region

1.9 Insect status of paddock

Rye in the paddock is generally free from insect pests. Where problems arise, growers should contact their local agronomist or relevant state government department for advice.

Although rye is susceptible to the same insects that attack other cereals, serious infestations are rare. Rye reduces insect pest problems in rotations and attracts significant numbers of beneficials such as ladybird beetles. [104]

103 SARE (2007) Cereal rye: Managing cover crops profitably. 3rd edn. SARE Handbook, Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

104 SARE (2007) Cereal rye: Managing cover crops profitably. 3rd edn. SARE Handbook, Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

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

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

1.9.1 Sampling of paddocks and soil for insects

Recent seasons have seen seemingly new pests and unusual damage in pulse and grain crops. Growers are advised to:

- Monitor crops frequently so as not to be caught out by new or existing pests.
- Look for and report any unusual pests or damage symptoms—photographs are useful.
- Just because a pest is present in large numbers in one year does not mean it will be so the next year. Another spasmodic pest may make its presence felt.
- Be aware of cultural practices that favour pests and rotate cops each year to minimise the build-up of pests and plant diseases. [105]

Sampling methods

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 to different sampling techniques.

Sweep net

The majority of crop monitoring for insect pests is done with a sweep net, or visually. Use of a shake/beating tray is an alternative. Sampling of 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 ~38 cm in diameter, and swept in a 180° arc from one side of the sweeper's body to the other. The net should pass through the crop at such an angle 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 five locations. After completing the sets of sweeps, counts should be averaged to give an overall estimate of abundance. Sweep nets tend to underestimate 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. [106]

Soil sampling by spade

Method:

1. Take a number of spade samples from random locations across the field.

105 H Brier H, M Miles (2015) Emerging insect threats in northern grain crops. GRDC Update Papers, July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Emerging-insect-threats-in-northern-grain-crops

106 DNPE Victoria (2000) Sampling methods for insects and mites. In Insectopedia—an electronic insect pest management manual for south-eastern Australian grain and pasture pests. The State of Victoria, Department of Natural Resources & Environment, http://ipmguidelinesforgrains.com.au/insectopedia/introduction/sampling.htm

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 two hours to initiate germination.
2. Bury a dessertspoon of the seed under 1 cm of soil at each corner of a square 5 m × 5 m at five widely spaced sites per 100 ha.
3. Mark the position of the seed baits, because large populations of soil insects can destroy the baits.
4. One day after seedling emergence, dig up the plants and count the insects.

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, use of the type of seed that is to be sown as a crop is likely to indicate the species of pests that could damage that crop. The major disadvantage of the method is the delay between the seed placement and assessment. [107]

1.9.2 Identification

The SARDI Entomology Unit provides an insect identification and advisory service. The unit identifies insects to the highest taxonomic level for species where possible and can give farmers biological information and guidelines for control. [108]

Insect ID: The Ute Guide

The Insect ID Ute Guide, available on Android and iPhone, 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 with which they may be confused. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [109]

App features:

- region selection
- predictive search by common and scientific names
- ability to compare photos of insects side-by-side with insects in the app
- identification of beneficial predators and parasites of insect pests

107 QDAFF (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/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects

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

109 GRDC (2016). Resources: Apps Grains Research and Development Corporation, https://grdc.com.au/Resources/Apps

- option to download content updates in-app with the latest pests affecting crops for each region
- ensures awareness of international bio-security pests.

1.9.3 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. [110]

Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil moisture retention, groundcover and soil biology, and this has affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity and influence beneficial species such as carabid and ladybird beetles, hoverflies and parasitic wasps. However, these systems also create conditions more favourable for many pests such as slugs, earwigs, weevils, beetles and many caterpillars. [111]

See Section 7: Insect control for more information.

Where paddock history, paddock conditions or pest numbers indicate a high risk of pest damage, a grower might decide to use pre-seeding control measures to reduce pest pressure, apply a seed dressing to protect the crop during the seedling stage and plan to apply a foliar insecticide if pest numbers reach a particular level. [112]

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 provide a food source for some soil insects; however, this can also mean that pests continue feeding on the stubble instead of germinating crops.
- No-till 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. Because 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. [113]

For more information, see Section 7: Insect Control.

MORE INFORMATION

Pest Genie Pty Ltd: Pest Genie

Australian Pesticides and Veterinary Medicines Authority: APVMA

110 R Jennings (2015) Growers chase pest-control answers. GRDC Ground Cover, June 2105, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers

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

112 G Jennings (2012) Integrating pest management. South Australian No-Till Farmers Association, Spring 2012, http://www.santfa.com.au/wp-content/uploads/Santfa-TCE-Spring-12-Integrating-pest-management.pdf

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

Pre-planting

Key messages

- Although cereal rye has been grown in Australia for more than 150 years, its agronomic development and breeding have been neglected compared with other winter-grown cereals.
- Rye is used for early sowings as a dual-purpose cereal, providing abundant, quick, early stock feed and as a grain-only crop. [1]
- Rye is relatively inexpensive and easy to establish, and outperforms all other cover crops on infertile, sandy or acidic soil or on poorly prepared land. It is widely adapted, but grows best in cool, temperate zones, especially southern Australia.
- Cereal rye helps to build soil structure, productivity and health, and reduce susceptibility to erosion.
- Ensure that seed quality is of a high standard. Check for damage and discoloration, because affected seeds may have poor germination and emergence.
- Rye seed deteriorates quickly after one year of storage. Ensure the seed is pure and has come from safe seed-storage conditions.
- Several strains and selections have been introduced into southern Australia at different times. They were referred to by names such as SA rye, South Australian Commercial rye, rye, cereal rye or ryecorn. Bevy is now the most widely grown variety. [2]

2.1 Cereal rye as an alternative crop

IN FOCUS

Cereal rye—an alternative grain crop

Potato growers near Ballarat, Victoria, traditionally grow rye as a green manure crop before planting potatoes in spring, and rye crops were rarely harvested for grain. Two flourmills that process rye products nearby obtain the bulk of their grain from 300–500 km away.

Farmers grow barley, wheat or oats in rotation with potatoes but due to low pH and high aluminum levels in the soil, wheat and barley crops frequently yield poorly or fail. Rye is known to be tolerant to these conditions and to the cold winters that prevail in the area.

The aim of this trial was to determine the potential for rye as an alternative grain crop.

Methods

Replicated field experiments were conducted near Springbank, (annual rainfall 900–950 mm) in 1986 and 1987. Separate experiments compared rates of sowing, varieties, growth regulators and nitrogen (N) fertiliser applied at various growth stages and rates.

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

2 Agriculture Victoria (2013) Growing cereal rye. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Results

A sowing rate of ~100 kg/ha gave the highest grain yield in 1986. In 1987, responses to N applied at early jointing stage were recorded at both low and high sowing rates (Table 1).

Table 1: *Effect of sowing rate on rye grain yield and protein.*

	1986 sowing rate:				**l.s.d. (*P* = 0.05)**
	50 kg/ha	**100 kg/ha**	**150 kg/ha**	**200 kg/ha**	
Grain yield (t/ha)	1.07	1.38	1.41	1.46	0.10
Grain protein (%)	14.2	13.3	13.0	12.3	
	1987 sowing rate ± 20 kg N/ha applied at jointing:				
	80 kg/ha	**140 kg/ha**	**80 kg/ha (+N)**	**140 kg/ha (+N)**	
Grain yield (t/ha)	3.07	3.31	3.69	3.74	0.23

Yield responses to growth regulator (Cycocel®) were measured in each year (Table 2.) Multiple applications and the addition of N further enhanced yield. Crop height was reduced by ~15 cm with each application.

Table 2: *Effect of Cycocel® growth regulator (CCC, applied at 293 g/ha) on rye grain yield.*

Zadoks decimal growth stage at application of CCC	**Rye yield (t/ha)**	
	1986	**1987**
Control (no CCC)	1.84	2.97
Z23	2.07	3.00
Z30	1.84	3.28
Z23 + Z30	–	3.40
Z23 + Z30 + Z40	–	4.25
l.s.d. (*P* = 0.05)	0.13	0,22

The trial demonstrated that rye can be successfully grown in high rainfall environments and that high grain yields can be achieved. [3]

2.1.1 Dual-purpose cropping

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 of cattle into similar weight ranges before they are placed onto grazing crops. Try to minimise handling and ensure that all animal health issues are addressed. [4]

3 K Bishop K (1989) Rye as an alternative cereal under high rainfall conditions. 5th Australian Agronomy Conference, http://www.regional.org.au/au/asa/1989/contributed/crop/p1-18.htm

4 K Harris (2016) Dual purpose crops. GRDC Update Papers, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Dual-purpose-crops

Dual-purpose crops can be a vital part of a mixed-business farming operation. Reliable dual-purpose crops require a high standard of agronomy including timely sowing, careful choice of variety, good subsoil moisture, and high soil fertility.

Dual-purpose winter crops, or grazing-only crops, can regularly gross $1,000–$1,500/ha with costs typically $300–$350/ha. In addition, they relieve pressure on the remaining grazing base (pastures), commonly giving them a chance to rest and be in an improved position to provide good feed when the dual-purpose crops are locked up for grain.

Dual-purpose crops supply quality feed in good quantities when other pastures are growing at a slow rate, especially in years with dry autumns (five of the last six years). [5]

Another advantage of grazing cereals is that if the season turns out favourably with adequate rainfall, farmers can also harvest grain yield from the paddock.

A successful strategy in the Mallee is to treat the paddock as a crop paddock and graze it rotationally until early to mid-tillering, and then shut the gate on livestock. If the paddock receives reasonable rain during July, there is a good opportunity for grain harvest; otherwise, the option exists of cutting for hay. Another successful strategy implemented by South Australian Mallee farmers (especially those who are more risk-averse) is to sow the paddock early merely for feed, and in favourable seasons when there is enough feed on offer in other paddocks, remove livestock from the grazed cereal paddock (before late tillering stage) and turn it into potential grain.

When selecting pasture for the farming system, a few points need to be taken into consideration, such as when and how much feed will be needed, quality of feed and possible animal health issues, weed competition and broadleaf weed control, fitting into farm rotation to provide early autumn feed, and a root disease break for future cropping.

Results from all Murray Mallee research/demonstration sites proved that all cereals could be safely grazed until their start of tillering (Zadoks growth stage Z26) without any yield penalty.

In trials at the Waikerie site, rye and wheat performed the best with respect to feed and gross income, followed by triticale and barley (Figure 1).

5 R Freebairn (2016) Profitable dual purpose cereals in the north and central west (a Purlewaugh case study). GRDC Update Papers, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Profitable-dual-purpose-cereals-in-the-north-west

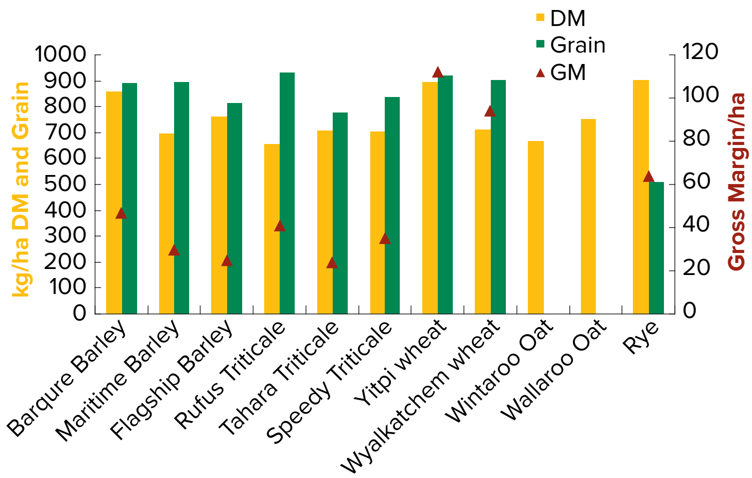

Figure 1: *Comparison of grain yield, dry matter (DM) and gross margin for grazing cereals at Waikerie, 2008.*

Source: Agronomy Matters

Cereal rye appears to be a viable option for Murray Mallee hilly and lighter soil paddocks, owing to its vigorous growth.

The majority of Mallee farmers tend to sow cereal rye just for grazing, but farmers who treated their cereal rye paddock as a crop paddock have been harvesting reasonable grain. Their strategy was to observe the forecast for opening rainfall and sow the paddock just before or after. In a few instances, farmers treated their grazing rye as crop, stopped grazing it around mid-tillering (Z28), and yielded 1 t/ha of rye grain. Considering the price of cereal rye, this seems a profitable trade.

Some other characteristics that make cereal rye a feasible dual-purpose cereal option are its early feed production compared with any other types of pasture, and high quality of feed (Figure 2). In addition, cereal rye usually makes a good break crop if the paddock is experiencing root and fungal disease. Grain quality was not affected by grazing or different seeding–fertiliser rates, although there were some fluctuations in screenings. [6]

6 Agronomy Matters (2009) Sustainable and productive pasture systems in the Murray Mallee—Final report summary. Agronomy Matters Vol 6, Issue 1, http://s3.amazonaws.com/zanran_storage/www.msfp.org.au/ContentPages/2479778786.pdf

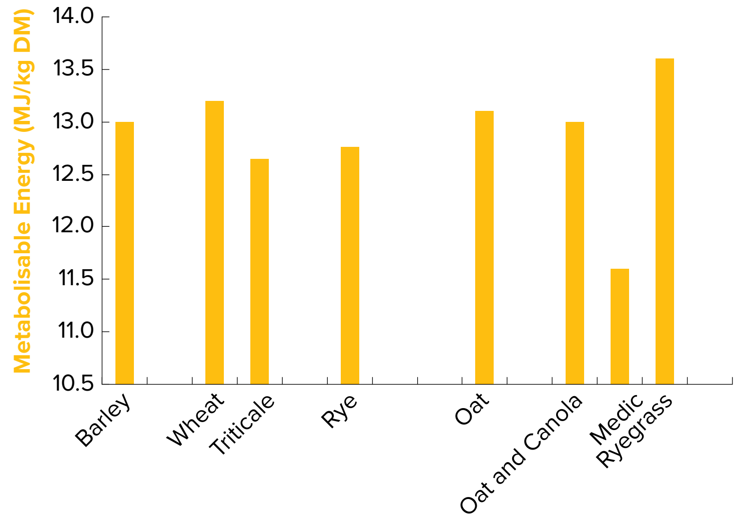

Figure 2: *Feed quality of different pasture options in the Mallee.*

Source: Agronomy Matters

With the support of the Grains Research and Development Corporation, NSW Department of Primary Industries managed a series of dual-purpose cereal cropping trials across New South Wales (NSW) at Somerton, Purlewaugh, Cowra and Culcairn.

The trials included the newest grazing varieties of wheat, triticale, cereal rye, oats and barley. Sown in mid-April, the crops in the northern areas had a difficult start with the drier conditions at sowing, but still produced some good results. All trials were assessed for dry matter (DM) production and were then grazed (Photo 1). A second DM assessment was taken later in the season. The crops were then allowed to develop through to harvest.

It was concluded that once grazing is finished and the crop is locked up for grain recovery, it should then treated as a grain crop, with the necessary nutritional (N), weed and disease management undertaken to maximise possible grain yields.

Photo 1: *Sheep grazing a dual-purpose crop.*

Source: GRDC

A highlight of the trial was the high early DM production from two new cereal ryes. It was the first time for several years that new cereal ryes were available that suited both grazing and grain recovery. These included Southern Green and Vampire⚲. Both varieties provided strong early growth and DM production, outperforming the traditional early feed producer oats at many of the sites. When looking for quick,

MORE INFORMATION

GRDC Fact Sheet: Dual-purpose crops. Bolstering feed supply to improve profitability and sustainability

GRDC Update Paper: Dual purpose crops

GRDC Update Paper: Dual purpose crops, do they have a fit in your system and how can they be managed to optimise forage and grain potential?

GRDC Update Paper: Dual purpose crops: economics and their management early DM production, the popular option has been oats, but now suitable cereal ryes are available.

Although the cereal ryes were quick to produce feed, their palatability dropped compared with the other cereals later in the season. Therefore, they should make up only a part of an overall forage production system. After the first grazing, the difference in production between crops (i.e. oats, rye, barley, triticale and wheat) narrowed significantly.

The trials also showed that grazing periods and rest periods were important for DM recovery. Generally, grazing too hard slows regrowth. Therefore, leaving some dry matter in the paddock will aid recovery from grazing and the stock can return to the paddock sooner. This could affect gross margins, because DM production and grain recovery are both important to the overall profitability of dual-purpose crops.

These DM values add up to a bonus for producers, with excellent returns from livestock enterprises as well as a profitable grain yield. [7]

VIDEOS

WATCH: Over the Fence south: Grain and graze combination delivers dollars at Raywood.

WATCH: Grazing dual purpose crops.

WATCH: Over the Fence: Grazing Crops: reaping big rewards and returns.

Importance of variety choice

On a property in 30 km east of Coonabarabran, NSW, spring-habit winter cereal varieties (cereal rye, oats, wheat, barley, triticale) sown in February or March commonly came to head in May, June or July, with time dependent on sowing time variety and environment. These crops commonly recovered slowly and often poorly after grazing.

By contrast, varieties with winter habit recovered far better after grazing, were less likely to be adversely affected by frost, and retained high quality for longer.

Winter habit is a characteristic whereby the growing point remains at ground level until a sufficient amount of cold weather triggers plants to change to spring habit, which means the head begins rising up the stem. Spring habit varieties have no such delay, with heads growing up the stem as soon as tillering occurs.

When animals graze below the growing point, which can be quite early for spring-habit types, the tiller dies and new tillers need to reform. Reforming of tillers can be slow, especially in the middle of winter and if soil-water supply is low.

Varieties differ in their levels of winter habit. This means that varieties with low winter-habit level will transfer to spring habit with heads growing up the stem after a shorter period of cold winter weather than varieties with high levels of winter habit. High levels of winter habit mean that the heads remain at ground level for a much longer period in a given environment.

Desirable level of winter habit is largely related to climate and purpose. For example, if the purpose is mainly early sowing and long grazing time over winter and spring, a variety with a high level of winter habit may suit best.

A dual-purpose role is more likely to suited best to a variety with moderate to lower levels of winter habit. This allows early sowing with no running to head too early, nor loss of tillers, and a period of 30–100 days grazing prior to locking up for grain recovery. Desirable length of grazing is variable and is related not only to variety type but also to sowing time (more if early) and seasonal conditions.

Climate also has a big role in choosing how much winter habit a variety should have. Colder areas have winter habit satisfied faster; therefore, varieties with greater winter habit are needed. By contrast, in warmer environments varieties with less winter habit are needed, unless used only for grazing.

Varieties with winter habit tend to grow slower at first than spring-habit types. This slower growth is usually of little consequence if sowing earlier, because the crop tends to make it up with better recovery post-grazing in winter–early spring. [8]

7 A Norris (2012) Dual purpose cereals shine. The Land, 25 February 2012, http://www.theland.com.au/story/3611427/dual-purpose-cereals-shine/

8 R Freebairn (2016) Profitable dual purpose cereals in the north and central west (a Purlewaugh case study). GRDC Update Papers, February 20016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Profitable-dual-purpose-cereals-in-the-north-west

2.1.2 Cereal rye for forage

Key points:

- Alternate forage cereal and legume pastures provide grazing opportunities at different times during the season.
- Choose varieties according to farm needs: ability to fill feed gaps; contribution to the farm's rotation in terms of nutrition, root and foliar disease management, weed control, and suitability for hay production.

Grazing of cereals is not a new technique in mixed-farming enterprises, but increased adoption of intensive cropping saw a reduction in its use.

In low-rainfall regions such as the Mallee, grazing of cereals seems to be working very well compared with other pasture systems that are not as reliable during the feed-shortage months (March–July).

There is a debate over whether to feed livestock with grain and hay, or with sown cereals for grazing during feed-shortage months. A cereal sown as pasture is a higher input option, but the amount of feed and the liveweight gain are significantly higher. [9]

Forage rye produces quick winter feed because it does not have a vernalisation (cold temperature) requirement and goes into reproductive mode almost immediately. Plants should be grazed early, before Z31 (stem elongation), to ensure two or three grazings. After Z31, grazed plants will not recover well and will lose palatability and feed quality. They are therefore not a good silage or hay option. Forage rye is best sown in combination with another forage, either as a mix or followed by a spring-sown summer forage. It can be grown in all rainfall areas, but as rainfall decreases, its ability to produce biomass and recover from grazing declines.

Based on trials in Culgoa (Victoria), forage rye was outstanding for early DM production relative to three other pasture types, reaching 416 kg DM/ha at Z14/21 (four-leaf stage, one tiller) on 5 July, only two weeks after sowing (Table 3). Ten days later on 15 July, forage rye had increased DM production by 469 kg/ha to 885 kg/ha, an exceptional production at this time of year.

Table 3: *Alternative pasture dry matter production (kg/ha) in trials at Culgoa in 2010.*

Pasture	5 July	15 July	14 October		Grain yield grazed (t/ha)
	Ungrazed	Ungrazed	Grazed	Ungrazed	
Forage rye	416	885	8,759	6,962	Not intended for harvest
Forage wheat	142	287	4,602	4,389	2.5
Oats–medic mix	160	255	4,952	3,262	1.44
Eastern star clover (*Trifolium dasyurum*)	41	56	4,799	1,569	Not harvested

Source: Online Farm Trials

All alternative pastures—forage rye, forage wheat and eastern star clover—showed potential as feed sources in 2011, filling feed gaps at different times and offering different end uses and rotation benefits. [10]

Similar results have been found in Tasmania. There were significant differences between the accumulated grazing DM yields of different varieties. Spring varieties of rye, barley, oats, and triticale showed rapid early growth and can be planted for feed supply early in winter. However, damage and/or removal of plant growing points

9 Agronomy Matters (2009) Sustainable and productive pasture systems in the Murray Mallee—Final report summary. Agronomy Matters Vol 6, Issue 1, http://s3.amazonaws.com/zanran_storage/www.msfp.org.au/ContentPages/2479778786.pdf

10 A Frischke, K Drever (2010) Alternative winter pastures. Online Farm Trials, http://www.farmtrials.com.au/trial/14012

reduced their subsequent regrowth, suggesting that the first cut was too severe; therefore, caution is required when grazing these types. [11]

For overall forage production, oats will generally produce more forage than will wheat, barley, cereal rye or triticale. The total amount of feed available will be influenced by the type of crop, variety, disease resistance and sowing time.

Cereals that produce large awns can cause mouth injuries to livestock and they should be avoided for hay production, or where head emergence under grazing cannot be controlled. These cereals include barley, triticale, cereal rye and some wheats.

Selecting crop types or varieties tolerant of root and/or leaf diseases will lessen the disease impact in susceptible situations. Where annual grass control (e.g. soft brome, barley grass and ryegrass) has been poor in the winter–spring prior to sowing, cereal root diseases are likely to cause serious production losses, particularly on non-acid soils. Highly susceptible crops such as wheat and barley should be avoided; cereal rye has good tolerance, with oats the next best, followed by triticale. Barley yellow dwarf virus (BYDV) can cause large losses of both dry matter and grain production, particularly in higher rainfall areas, when susceptible crops (especially oats and barley) are sown early. Tolerance of BYDV will therefore influence crop and variety choice.

Quality tests on the forage of cereal rye, oats, wheat, barley and triticale, when grown under similar conditions, show no significant differences in levels of protein, energy and digestibility. Therefore, a cereal with higher grain returns may be chosen as an alternative to oats. [12] Feed test results from Ballarat in 2008 show that rye varieties were as good as, or better than, other forages with respect to feed quality (Table 4).

Table 4: *Feed test results from Ballarat Winter Feed trial in 2008, with samples taken 22 July 2008.*

Variety	Dry matter (%)	Crude protein (%)	Neutral detergent fibre (%)	Dry matter digestibility (%)	Metabolisable energy (MJ/kg DM)
Southern Green rye	9.9	33.6	36.7	81.6	12.5
Common rye	9.7	32.7	36.8	79.5	12.0
Forage oats	9.8	31.9	36.5	81.7	12.5
Italian ryegrass	10.7	32.3	34.0	81.4	12.4
Appin leafy turnip	7.1	34.8	20.1	87.2	13.4

Source: Forage Focus

Ideally, only be one type of cereal should be sown in a paddock, as stock will preferentially graze one cereal over another.

2.1.3 Break or cover cropping

Cover crops are crops that are planted primarily for the benefits they provide to the soil. Interest in cover crops is increasing in Australia, driven by groups such as the Victorian No-Till Farmers Association.

Cover cropping has the potential to reduce herbicide reliance and minimise tillage while improving soil fertility, reducing soil erosion, sequestering soil carbon, increasing soil water infiltration and storage, and suppressing weeds. [13]

11 G Dean, A Merry, R Smith (2015) Evaluation of short-term fodder options between cropping phases in Tasmania. 17th Australian Agronomy Conference, http://www.agronomy2015.com.au/papers/agronomy2015final00240.pdf

12 G Hennessy, B Clements (2009) Cereals for grazing. Primefact 720, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/288191/Cereals-for-grazing.pdf

13 SB Mirsky, WS Curran, D Mortensen,MR Ryan, DL Shumway (2009) Control of cereal rye with a roller/crimper as influenced by cover crop phenology. *Agronomy Journal* 101, 1589–1596.

VIDEOS

WATCH: The importance of Crop rotation.

Cover crops are an important addition to farming systems to improve soil quality and decrease soil erosion or nutrient loss. According to assessments in Iowa, USA, cover crops on average can reduce N loading by 28% and phosphorus loading by 50%. In view of these benefits, research was done identify any effects of a cereal rye cover crop on yields of maize and soybean cash crops. Since 2008, 46 site-years have been conducted, with farmers reporting that in 42 of 46 site-years, properly managed cover crops had little or no negative effect on maize and soybean yield (and actually increased soybean yield in four site-years). [14]

Cover-crop mixtures

Cover crops can be planted as a single species or in mixtures. The most common mixtures include a legume such as vetch and a cereal grain such as rye (Photo 2). Mixtures provide advantages and disadvantages compared with single species.

In a rye–hairy vetch, mixture, rye protects the vetch during establishment and throughout the winter, and provides physical support for the climbing vetch during the spring growth period. The rye also protects the soil from winter erosion better than a pure stand of vetch. The amount of N available to the subsequent crop is not as great as with a pure vetch stand. In addition, more N is tied up during decomposition of the mixture due to the higher carbon to N ratio of the rye. [15]

Lodging can be a problem with cereal rye, and sowing rate is therefore an important consideration.

Photo 2: *A mixture of hairy vetch plus rye can produce a lot of biomass that can enhance soil quality while providing a significant amount of nitrogen to a subsequent crop.*

Source: University of Vermont

14 S Gailans (2015) Winter cereal rye cover crop effect on cash crop yield: results from long-term, on-farm research. In Synergy in Science 2015: Partnering for Solutions, ASA/CSSA/SSSA Annual Meeting, https://scisoc.confex.com/scisoc/2015am/webprogram/Paper91725.html

15 WS Curran, DD Lingenfelter, L Garling, P Wagoner (2006) Cover crops for conservation tillage systems. Conservation Tillage Series 5. Penn State Extension, http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/cover-crops-for-conservation-tillage-systems

Break benefits on Mallee soils

Take home messages

- Break options including a low-cost volunteer medic-based pasture have led to wheat yield gains of over 0.7 t/ha on some soils and in some cases significant effects in the third year after the break.
- Across a range of soil types, seasons and break types, breaks have led to a typical cumulative benefit of almost 1 t/ha of wheat.
- This relatively consistent level of benefit is likely to be the result of a changing range of physical, chemical and biological drivers that differ across soils, season and break types.
- Canola greatly reduced risk of Rhizoctonia disease compared with other options.
- Pasture provided the highest N mineralisation potential in the second wheat crop.
- Although yield effects of break crops were generally similar across the soil types, there are considerable differences in gross-margin benefits due to the differences in break crop yields and wheat yields that could have been achieved when the break option was grown.
- The ability to reduce the opportunity cost of growing break crops, and taking advantage of potential for second- and third-year break effects, are important for maximising the value from break options.

Wheat is a relatively low-risk crop, but relying on continuous cropping can increase vulnerability to weeds, disease and declining nutrition and lead to increased costs. The inclusion of break crops can address these issues, but in a low-rainfall environment this often involves growing a crop that is riskier than cereal.

Several field trials in the Mallee have examined both the performance of break crops and their impact on the performance of subsequent wheat crops. At Karoonda, South Australia, the effects of a range of break crops and a low-cost, medic-based pasture were evaluated over three subsequent wheat crops. The study highlighted the importance of evaluating the benefits of break crops (or pasture) over several years, and that often there are different drivers of the break effect (e.g. disease, nutrition, stored soil water) across different soil types and seasons. [16]

Evaluating break crops

Trials were established at Karoonda (337 mm average annual rainfall) on different soils ranging from heavy swale to deep sand dune. Single-year break crops were grown in 2010 and 2011 comprising legume (field peas and lupins), canola, rye (grain and 'grain + graze') and volunteer pasture on a paddock that had a cereal history of at least four years. Wheat was grown following break crops with 16 kg N/ha applied as urea and 9 kg N/ha as di-ammonium phosphate, all at seeding, in addition to phosphorus, sulfur and micronutrients. Yields are shown in Table 5.

16 R Llewellyn, T McBeath, B Davoren, V Gupta, M Moodie, B Jones (2013) Break benefits on Mallee Soils—the long and the short. GRDC Update Paper, July 2013https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Break-benefits-on-Mallee-soils

Table 5: *Grain yields (t/ha) of different crop types on each soil type in 2009–12, with mid-slope split into mid-top and mid-bottom in 2010.*
Within a season, soil × crop type combinations followed by the same letter are not significantly different at P = 0.05.

	Dune	Mid-top	Mid-bottom	Swale
2009				
Rye	1.78a	1.86a		0.81de
Rye (cut)	0.90de	1.06cd		0.53e
Field peas	0.59e	0.69de		0.69de
Wheat	1.77ab	1.94a		1.40bc
l.s.d. (P = 0.05)	0.38			
2010				
Canola	1.87i	1.14j	1.35j	2.04hi
Rye	3.10de	2.88ef	3.43cd	3.36cde
Rye (cut)	2.39gh	1.92hi	2.39gh	2.32ghi
Lupins	3.80bc	4.00b	3.27de	2.55fg
Wheat	2.99def	2.24ghi	4.03b	5.17a
l.s.d. (P = 0.05)	0.48			
2011				
Wheat	3.60	2.17	3.47	3.75
2012				
Wheat	2.09	1.30	2.56	3.43

Source: GRDC

In 2010, the best break effect was following field peas (+0.93 t/ha) and pasture (+0.83 t/ha) when averaged across all soils. In 2011, the first-year break effects followed a similar pattern (Figure 5). In general, soil type was found not to be a statistically significant influence on the break effects.

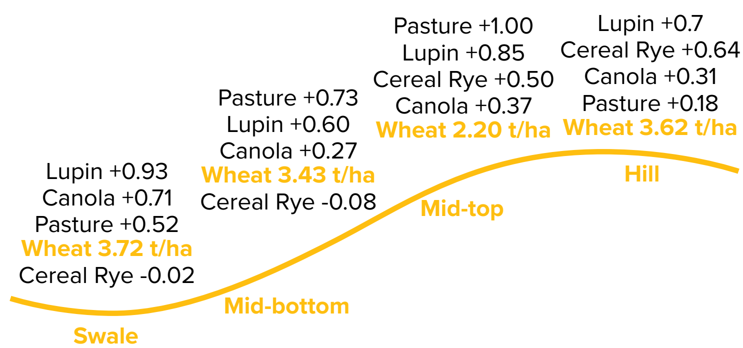

Figure 3: *Yield gain in the 2011 wheat crops following various break crops grown in 2010 at Karoonda. Continuous wheat yields for 2011 are shown in the black boxes. (l.s.d. (P = 0.05): swale, 0.42 t/ha; mid-bottom, 0.41 t/ha; mid-top, 0.49 t/ha; hill, 0.53 t/ha).*

Source: GRDC

Both field peas and pasture caused a significant second-year effect on wheat production in 2011. In 2012, there were some significant second-year break effects with lupins, pasture and canola all leading to significant wheat yield gains compared with continuous wheat. Pasture grown in 2009 led to a statistically significant third-year break effect (in 2012).

The benefits of breaks are relatively consistent in terms of the gains in wheat yield, irrespective of wheat crop yield, soil type or the range of break options. The cumulative effect of the breaks over 3 years is shown in Figure 4. A big yield boost in year 1 after a break can sometimes come with reduced benefits in year 2. The results so far show that the breaks have led to a total benefit of almost 1 t/ha of wheat over 3 years across the range of soils and break types.

Figure 4: *Cumulative yield of wheat over 3 years after breaks showing benefit of breaks compared with continuous wheat (1:1 line is presented).*

Source: GRDC

The drivers for the break effects vary across soils, break types and seasons. They included increased soil available N, higher available soil water levels at sowing following breaks, and disease differences.

An example of potential disease risk reduction is shown in Figure 5. Cereal crops have promoted the build-up of *Rhizoctonia solani* inoculum, whereas canola reduced inoculum levels. *Rhizoctonia* inoculum was lowest after the canola crop and highest after the wheat crop across all soils.

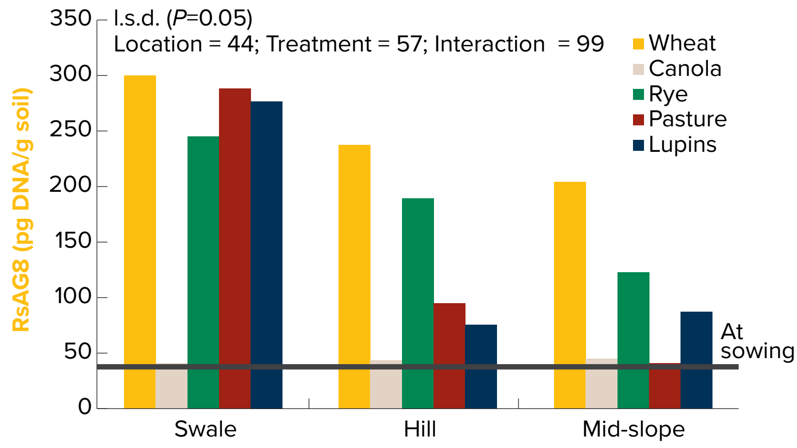

Figure 5: *Inoculum levels of Rhizoctonia solani (Rs) AG8 measured in 2011 following different crops grown in 2010 (Gupta et al. 2011, in collaboration with GRDC project CSP00150—Managing Rhizoctonia disease risk in cereals).*

Source: GRDC

The strong performance of the volunteer pasture, which had a medic base but was not maintained grass-free, is partly explained by the estimated N mineralisation potential shown in Figure 6. Soil that was under pasture in 2010 had significantly more potential to supply N to the 2012 crop than soil on which break crops were grown in 2010.

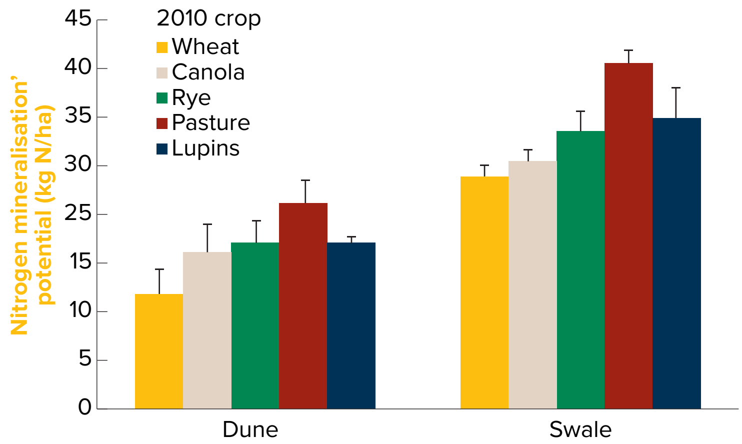

Figure 6: *Effect of 2010 break crops on N mineralisation potential (estimate for decile 5 season) measured at time of sowing in 2012.*

Source: GRDC

Four-year cumulative gross margins were calculated for each soil type × crop sequence combination where breaks were grown in 2009 (Table 6). Although the effects of break crops on wheat yield were generally similar across the soil types, there were considerable differences in relative gross margins due to the differences in the yields of the break crops and the wheat yields that could have been achieved when the break option was grown in 2009.

Table 6: *Gains in cumulative gross margin from break crops relative to continuous wheat across different soil types.*

Rotation				Swale	Mid-bottom	Mid-top	Hill
2009	**2010**	**2011**	**2012**	**$/ha**	**$/ha**	**$/ha**	**$/ha**
Field peas	Wheat	Wheat	Wheat	+283	+113	+52	+80
Rye grain	Wheat	Wheat	Wheat	+75	+62	+119	+112
Rye grazed	Wheat	Wheat	Wheat	+301	–133	+60	–217
Pasture	Wheat	Wheat	Wheat	+250	+74	+233	+191

The costs were calculated using the Rural Solutions Farm Gross Margin Guide; grain prices are five-year average, pasture biomass valued at $35/t/ha. Gains (or losses) are presented relative to the cumulative gross margin for the four years of continuous wheat (swale $2989/ha, mid-bottom $2488/ha, mid-top $1267/ha and dune $2038/ha).

Source: GRDC

Where breaks were grown in the relatively poor-yielding year of 2009, profitability over the 4-year sequence was generally higher than continuous wheat (Table 6). This was particularly the case on the swale, where wheat performed poorly in 2009. Breaks grown on the swale in 2010 were expected to be less profitable over the sequence because wheat would have been a highly profitable option in that year.

Given the possibility of benefits in the third year following the breaks, the trial was continued into 2013 to evaluate the longer term profitability of break options grown in 2010. [17]

Control of cover crops

Cover crops that interfere with growth of primary crops defeat their purpose. Effective control or suppression of the cover crop is generally necessary before emergence of the main crop. Commonly used methods include tillage, mowing, herbicides, or selection of species that winterkill or have a short life cycle. [18]

In the absence of herbicides, cereal rye cover crops are typically terminated with tillage, or with mowing in no-till situations. Mowing has several drawbacks including the risk of regrowth, accelerated residue decomposition, and patchy distribution of the surface residue. Uniformity of coverage of surface soil from cover-crop residue is critical for optimising weed suppression. A roller–crimper is a viable alternative to mowing and tillage (Photo 3). The residue is deposited uniformly on the soil surface. The resulting layer of rye residue persists for longer than with mowing, enhancing weed suppression, moisture retention, and soil conservation. [19]

17 R Llewellyn, T McBeath, B Davoren, V Gupta, M Moodie, B Jones (2013) Break benefits on Mallee Soils—the long and the short. GRDC Update Paper, July 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Break-benefits-on-Mallee-soils

18 W Curran, DD Lingenfelter, L Garling, P Wagoner (2006) Cover crops for conservation tillage systems. Conservation Tillage Series Number Five. Pennsylvania State University, http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/cover-crops-for-conservation-tillage-systems

19 SB Mirsky, WS Curran, DA Mortensen, MR Ryan, DL Shumway (2009) Control of cereal rye with a roller/crimper as influenced by cover crop phenology. *Agronomy Journal* 101, 1589–1596.

Photo 3: *Well-designed roller–crimpers, and a good management plan, can help no-tillers and strip-tillers to smother weeds, improve soil protection and get the most from high-biomass cover crops.*

Source: No-Till Farmer

Rye should not be used as a cover crop just before growing other cereal grains. Volunteer rye may contaminate wheat, oats and barley. [20]

Under stressful conditions such as those found in tilled and chemical fallow fields, grassy field edges and roadsides, rye plants can still grow and produce seed despite attaining heights of only 25 cm or less (Photo 4). [21]

Photo 4: *Shorter stands of cereal rye can still produce seed heads.*

Source: NebGuide

Tillage not only controls cover crops, it also incorporates them into the soil, allowing them to degrade quickly and release nutrients for the primary crop. An example of incorporation is a cover crop used as a green manure. Mouldboard ploughing may be necessary if large amounts of cover crop biomass are present. Chisel ploughing followed by discing may be inadequate for certain cover crops such as cereal rye if large amounts of residue are present. If timed properly, mowing can successfully control certain covers prior to planting the primary crop. To insure successful control, producers should mow cereal grains after heading; mowing prior to head emergence will likely result in regrowth from tillers. Regrowth from cereal grains harvested for

20 Manure $ense (2009) Cereal Rye: Manure and Livestock's new best friend. Michigan State University Extension, http://mccc.msu.edu/wp-content/uploads/2016/09/MI_2009_CerealRyeManure.pdf

21 D Lyon, R Klein (2007) Rye control in winter wheat. University of Nebraska, https://web.archive.org/web/20140413144910/http://www.ianrpubs.unl.edu/pages/publicationD.jsp?publicationId=106

forage in the boot stage of development is a common problem for producers who do not use an appropriate herbicide program or tillage. [22]

IN FOCUS

Control of cereal rye with a roller/crimper as influenced by cover crop phenology

Adoption of reduced-tillage practices have been driven by the need to enhance soil quality, minimise field labor time, and scale up farm size. However, concerns about increased reliance on herbicides and demand for organically grown foods call for adoption of production practices that can reduce both tillage and herbicide use. This study assessed the influence of planting and termination dates on efficacy of mechanical cover-crop control (by roller–crimper) to limit tillage and herbicide use. A thermal-based phenological model using growing degree-days (GDD; base 4.4°C) was developed to predict cereal-rye growth stage. Mechanical control of cereal rye increased as rye matured. Variations in growth rates of cultivars were observed; however, they responded similarly to rolling when terminated at the same growth stage. Consistent control was achieved at Z61 (rye anthesis). A thermal-based phenological model separating the effects of heat units accumulated in autumn from those accumulated in the spring best predicted the phenological development of cereal rye. Predicting when cereal rye can be successfully controlled with a roller–crimper along with the use of the thermal-based phenological model should aid growers in decision-making regarding cereal rye planting and termination dates. [23]

VIDEOS

WATCH: Over the Fence: Cover crop ensures soil moisture.

Prevention of wind erosion

Cereal rye can establish well on poor, windblown sand. It has four primary roots that originate from the seed and can send out roots and tillers from the second, third and fourth node. This extensive root system within the first 30 cm of soil is more developed than in other cereals. It can withstand greater sowing depths, which is useful when sowing over eroded or disturbed sites or where depth is hard to control, and it makes the plant more drought-resistant.

Cereal rye straw and grain are the least preferred fodder for sheep; this aids in the recovery of wind-eroded soils, because sheep will graze other stubbles before turning to rye stubble. An on-farm trial in Western Australia found that rye was successful in preventing further erosion. Approximately 80% of land cropped to rye recovered sufficiently to return to normal rotation. However, disease became an issue after three years of continuous rye. [24]

Cereal rye is the plant commonly used for reclamation on the solonised brown soils that make up a large part of the low-yielding wheat lands of southern Australia. They lie largely in a zone of low rainfall, ~225–375 mm per annum of unreliable, winter incidence. Soils are deep sandy to shallow loamy soils overlying deep rubbly and powdery calcareous clay subsoils, and are neutral to alkaline at the surface, becoming more alkaline with depth. Their landscape is frequently characterised by a parallel east–west dune system. They are farmed on a wide rotation, comprising volunteer pasture–fallow–wheat, in which superphosphate is used solely with

22 WS Curran, DD Lingenfelter, L Garling, P Wagoner (2006) Cover crops for conservation tillage systems. Conservation Tillage Series 5. Penn State Extension, http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/cover-crops-for-conservation-tillage-systems

23 SB Mirsky, WS Curran, D Mortensen,MR Ryan, DL Shumway (2009) Control of cereal rye with a roller/crimper as influenced by cover crop phenology. *Agronomy Journal* 101, 1589–1596.

24 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

the wheat. Sheep graze the pastures. These soils, especially the sands, are very susceptible to wind erosion, and much effort is devoted to stabilisation of the once-cleared and cultivated dunes. [25]

2.2 Varietal performance and ratings

Rye is a cross-pollinated plant, and when seed is grown in a particular environment for a period of years, types more suitable to that environment evolve by natural selection.

The cultivar types or strains most commonly grown have fast and erect early growth and are of early maturity.

The cultivar South Australian was a popular early crop and was widely grown in South Australia, Victoria and Western Australia. [26]

New varieties have since been bred and incorporated into growers' rotations.

2.2.1 Identifying products for industry

A project funded by the GDRC aimed to deliver new products for the rye industry. [27]

Low- and high-amylose rye

Low-amylose or sticky ryes were anticipated to be of use for food products such as breakfast cereals and crispbreads, as well as feed for ruminants and monogastrics.

Both high and low amylose ryes were identified. The low lines had amylose contents of 6–10%. Nine high amylose lines were identified with a range in amylose of 33–37%. The low amylose materials were kept in storage for potential future use.

In 2004, the high-amylose ryes were used in crosses with high-amylose durum wheats with a view to developing high-amylose triticales.

Low- and high-pentosan rye

Low viscosity rye was seen as a priority for the feed industry, whereby a significant reduction in pentosans was perceived to be of value for monogastric nutrition.

Twelve very low pentosan lines gave rise to a population of 100–200 low viscosity lines, which were selected for field-testing. The materials were put into storage.

George Weston Foods tested the baking of some low pentosan lines. Low pentosan lines gave a better baking response using local technology (30% rye flour, 70% wheat flour) than the normal or high-pentosan rye lines.

Industry expressed an interest in high-pentosan rye believing that this would be of benefit to bread volume and quality parameters such as reduced staling and dietary considerations.

High-viscosity lines were identified and sown in the field in 1998. A high-pentosan population (HP) was identified and built up but it did not have expected improvements in bread volume. This rye population was also tested in 2004 as a rye for grazing for the Queensland cattle industry.

White rye

White rye was intended for a specialty niche market, and consideration was given to the preference for white breads and to the development of a white crispbread from cereal rye.

25 ABS (2001) The soils of Australia. ABS Feature Articles 1966. Australian Bureau of Statistics, http://www.abs.gov.au/ausstats/abs@.nsf/Previousproducts/1301.0Feature%20Article801966

26 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

27 GRDC (1998) Project US200 Cereal Rye—New products for industry. GRDC Final Reports, http://finalreports.grdc.com.au/US200

From a population that was originally very tall, several good agronomic types of normal height were selected following identification of fixed white lines both selfing and inter-mating.

Following further selection and yield trials, a white-seeded population was increased for commercial release. The white rye could also be used in crosses with white durum with a view to developing additional sources of white triticale.

High-molecular-weight glutenin rye

High molecular weight (HMW) glutenin rye was seen as important to the bread making industry, i.e. for high loaf volume.

A rye line carrying a wheat–rye translocation was supplied by Professor Adam Lukaszewski (University of California, Riverside), and this line showed some improvement in baking quality. However, the translocation had also been shown to reduce the yield by 30%. This HMW glutenin rye was crossed with the best local rye germplasm, and the material grown for a further cycle before being put into storage.

Long-season dual-purpose rye

Numerous rye lines were developed that had the dual-purpose (graze-and-grain) capacity of the earlier variety, Ryesun. Dual-purpose trials were conducted at the Cowra Research Station, NSW, and several promising lines were identified.

Feedback from growers in South Australia indicated that taller rye varieties (unlike the dwarf variety Bevy) were preferred for feed purposes.

The development of dual-purpose ryes and the high-yielding variety Westwood was the result of ongoing breeding, trialing and selection for quality traits. Westwood was released commercially in 2003, being least 10% higher yielding than Ryesun in NSW, and with improved lodging resistance. [28]

2.2.2 Developing products for industry

The aim of a follow-up GRDC project was to produce higher yielding rye varieties with new end uses. [29]

Cereal rye is suited to the acid soils of central and southern NSW and the sandy soils of the South Australian Mallee. Its main use is for rye breads (30–50% rye flour) or kibble in multigrain bread. Rye is very high in soluble fibre and is therefore of benefit to human health.

The new varieties to be developed included a higher soluble-pentosan rye and a white rye suitable for NSW, and a rye suitable for the South Australian Mallee.

A high-yielding, open-pollinated rye with improved levels of soluble pentosans was developed. A white-seeded rye line was also produced. The new rye line for South Australia was not as high yielding as Bevy.

The high pentosan rye, coded HP Rye, has the desired quality characteristics for rye bread and kibble. It yields 5–10% better than Ryesun, has better lodging resistance than Ryesun, and is a good graze-and-grain line for rye growers in NSW. HP Rye is a combination of 11 high-pentosan lines from a population comprising Australian and European germplasm that had been allowed to randomly cross (rye is a cross-pollinating species). Selection of lines for the mixture (synthetic) was based on adjusted yield results from Cowra in 2002 and subsequent tests for soluble pentosans.

The white rye synthetic, produced from 13 white-seeded selections, was 10–15% lower yielding than Ryesun and taller. In quality analysis by Westons, it produced a poor rye loaf due to underlying quality problems and the method used to produce rye bread in Australia.

28 GRDC (1998) Project US200 Cereal Rye—New products for industry. GRDC Final Reports, http://finalreports.grdc.com.au/US200

29 GRDC Project US00022 (2005) Rye—New products for industry, http://finalreports.grdc.com.au/US00022

Opportunities

The outstanding yields of the new hybrid ryes offer opportunities for the development of new and improved products for:

- Biofuel. Hybrid rye now outyields most other cereals and can be grown on marginal land, therefore not affecting the current food and feed requirements for other cereal grains.
- White bread-making rye. The rye industry would benefit substantially from a high baking rye, which would reduce the need for the addition of wheat flour (70%) in rye loaves. This option is possible by using white grain triticales with excellent bread making characteristics that can be crossed with new and existing sources of white rye. [30]

Growers should be aware that cereal rye is a cross-pollinating species and it will outcross. To maintain pure seed and varietal type, growers should regularly source new seed. The availability of seed of the older cereal rye varieties is limited and some could no longer be under commercial seed production.

2.2.3 Varieties

Bevy

Bevy is higher yielding than SA Commercial (SAC) rye and a direct replacement. Bevy was developed at the University of Adelaide from a composite of nine predominantly semi-dwarf spring rye types. Most plants (80%) are semi-dwarf, with 15% as tall as SAC and 5% very short. When mature, heads also range in length.

Bevy flowers about two weeks later than SAC, and this later maturity may assist in avoiding effects of frost. The yield of SA Commercial is frequently frost-affected, whereas Bevy may escape.

Compared with SAC, Bevy has increased seedling vigour and superior tillering ability and is the most suitable cereal for fragile sandy soils. It is well adapted to Mallee environments and has performed far better than SAC in longer growing seasons.

The milling yield of Bevy is slightly better than SAC and baking quality is similar. Bevy has slightly smaller seed, marginally lower 1000-grain weight and a smaller proportion of very dark grains than SAC.

Bevy is superior to SAC for stem and leaf rust resistance. [31]

Bevy is resistant to cereal cyst nematode (CCN) and is a poor host to the root-lesion nematode *Pratylenchus neglectus*, meaning that it can be useful to manage these diseases. However, Bevy is a host for the root disease take-all, and this should be carefully monitored. [32]

Bevy is the primary variety used for rye grain production, with most other varieties primarily used for forage purposes.

MORE INFORMATION

Teague Australia: Bevy

Southern Green forage rye

Southern Green is a forage rye that was developed for very rapid growth to first grazing. It has high tiller density and leaf development, and strong tiller survival after initial grazing. It has a spring habit, but is likely to lodge under good conditions. It is marketed by PGG Wrightson Seeds. [33]

Key points:

30 GRDC Project US00022 (2005) Rye—New products for industry, http://finalreports.grdc.com.au/US00022

31 R Saunders, R Wheeler. Bevy. Teague Australia, http://www.teague.com.au/members/pdf/9749370EA20CA886DBF1899.PDF

32 Agriculture Victoria (2013) Growing cereal rye. Victorian state Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

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

- Southern Green forage rye is bred for quick winter feed—ready to graze in 30–55 days. Some brassicas may be quicker with a March break but Southern Green grows quickly even if the break is late.
- It can produce twice the DM of oats at 45 days after sowing (Photo 5).
- In a trial, by late July (90–100 days after sowing) oat growth rates have increased but cereal rye was still 30% ahead in DM yield.

Southern Green is a much more uniform and leafy crop than common cereal rye. It is also early maturing and earlier to reach stem elongation than most other cereals. It will bolt to head in autumn if planted early and not grazed. It is for quick feed and must be used.

Because of its lack of vernalisation requirement, Southern Green will go into reproductive mode almost immediately. This habit is the driver of quick winter feed production, but means it can be damaged easily by overgrazing.

Photo 5: *Ballarat Winter Feed Trial (sown 21 April 2008). Southern Green forage rye (left) Wintaroo Oats (right). Photo taken 45 days after planting. Southern Green is ready for a graze where Wintaroo would be damaged by grazing at this early development stage.*

Source: Wrightson Seeds

After winter grazings, a spring brassica can be sown into thinned out Southern Green; the scattered regrowth may set seed and regenerate well from the seed the following year.

Cereal rye's resistance and tolerance to CCN make Southern Green a valuable rotation option on lighter soils where CCN is often severe. Resistance and tolerance to take-all make rye varieties such as Southern Green a useful break crop for sowing before susceptible wheat, triticale or barley crops. It can also be sown in situations where take-all is expected—following grassy pasture on soils that are unsuitable for oats. (Note that the variety Bevy does not have resistance to take-all.) Forage rye such as Southern Green used in rotation may reduce the severity of wheat leaf diseases *Septoria tritici* blotch, glume blotch and yellow leaf spot, and the barley leaf diseases scald and leaf net blotch. [34]

34 Wrightson Seeds (2010) Forage focus—Southern Green forage ryecorn, http://www.pggwrightsonseeds.com.au/assets/FTP-Uploads/Forage_Focus/Cereals/FF_Southern-Green-Forage-Ryecorn.pdf

MORE INFORMATION

Wrightson Seeds: Southern Green forage ryecorn

Grazing management

Timing of early grazing is critical if regrowth is wanted. In the 2008 Ballarat Winter Feed trials (Photo 5 above) where rain delayed the first harvest (trial was 95 days to the first cut), Southern Green had its growing points removed by the mower and regrowth was reduced.

If the first grazing is early, before stem elongation (Z31), Southern Green has the potential to give three grazings. However, if Southern Green reaches 25 cm growth, it may have initiated stem elongation (>Z31) and may provide only one or two grazings. This is because the growing point may be removed and further tillers are unlikely.

Southern Green can be left for one large grazing in mid-August at early stem elongation, or for an early silage cut in very dry areas or drought years. Management of the first grazing is similar to that for other cereals (e.g. oats) because the secondary roots are not developed until after the first grazing, or when plants are reasonably advanced. Therefore, the first grazing should be not too heavy, or should be by sheep rather than cattle. [35]

Ryesun

A main-season variety with adequate stem rust resistance. It is likely to lodge under good conditions. Ryesun is an early variety with dual-purpose capacity.

Ryesun and the traditional variety SAC were compared over two years. In both years, Rysun significantly outyielded SAC by ~20%. [36]

Vampire(D

Vampire(D cereal rye is recommended for its extremely vigorous growth and for early grazing. It is suitable for grazing and grain recovery. It is very suited to poor soils and revegetation projects.

Vampire(D is a main-season variety. It has good tolerance of acid soils and high aluminium, and it has improved lodging resistance and grain yield compared with Ryesun.

Vampire(D is suited to rotation for suppression of root-lesion nematode. [37]

Released by the University of Sydney and marketed by Waratah Seed Company, Vampire(D was selected for its long coleoptile length (i.e. improved early vigour, see Photo 6) and excellent early DM production. It can be grazed by stock within four weeks.

Vampire(D is an option if a summer crop was planned or a triticale pasture–silage mix. It suits autumn–winter sowing for five months' feed, can be sown before summer crop (rape, lucerne, etc.), and has the potential to give three grazings. [38]

Grazing management

The first grazing can be light to promote growth and secondary root development; this can be followed by second grazing before stem elongation or third grazing to graze out the crop for spring sowing. It can also be left for one large grazing in winter. Recommended sowing rate is 40–50 kg/ha.

35 Wrightson Seeds (2010) Forage focus—Southern Green forage ryecorn, http://www.pggwrightsonseeds.com.au/assets/FTP-Uploads/Forage_Focus/Cereals/FF_Southern-Green-Forage-Ryecorn.pdf

36 K Bishop (1989) Rye as an alternative cereal under high rainfall conditions, http://www.regional.org.au/au/asa/1989/contributed/crop/p1-18.htm

37 Hart Bros Seeds, http://www.hartbrosseeds.com.au/all-products/vampire-ryecorn.aspx

38 AGF Seeds. Vampire forage rye-corn. Australian Grain and Forage Seeds, https://agfseeds.com.au/ryecorn

Photo 6: *Chew and chop cereal blend including Vampire⚲ (left), and other commercial forage cereal (right) at seven weeks post-sowing, demonstrating early vigour in Vampire⚲.*

Source: AGF Seeds

Westwood

Westwood is a main-season variety with maturity similar to Ryesun. It has adequate stem and leaf rust resistance. Westwood was released commercially in 2003. It is at least 10% higher yielding than Rysun in NSW, and has improved lodging resistance. [39] [40]

2.3 Quality of planting seed

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 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. [41]

Seed should be free of weeds and ergot bodies (*Claviceps purpurea*), and have at least 85% germination. Stored rye seed loses its ability to germinate more rapidly than seed of other cereals. It is recommended to buy certified seed, which has proven adaptation to local conditions. Fungicide seed treatments used for other cereal grains are suitable for use on rye and can often improve stands. [42]

Rye seed should be cleaned thoroughly to remove weed seeds, foreign material (including ergot) and cracked kernels. Ergot bodies must be removed to prevent re-infestation of fields. Use of pedigreed seed ensures high quality. There are no ergot-resistant rye varieties. The only practical control is to sow clean, year-old seed on land that has not grown rye for at least one year. [43]

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39 NSW DPI (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

40 GRDC (1998) Cereal rye—new products for industry. GRDC Project US200, Final Report, http://finalreports.grdc.com.au/US200

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

42 EA Oelke, ES Oplinger, H Bahri, BR. Durgan, DH Putnam, JD Doll, KA Kelling (1990) Alternative field crops manual: Rye. University of Wisconsin Cooperative or Extension Service, https://hort.purdue.edu/newcrop/afcm/rye.html

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

Heat damage causes slower germination, delayed emergence of the primary leaf, stunted growth or termination of the germination process. In severe cases, seed death may occur (Photo 7). During bulk storage, areas of excessive moisture can lead to microbially induced 'hot spots', and because moisture moves from hot to cooler areas, further local heating is caused in a chain reaction. [44]

MORE INFORMATION

GRDC Fact Sheet: Retaining seed: saving weather-damaged grain for seed

Photo 7: *Normal cereal seed (left) and heat-damaged seed (right). Note the colour difference.*

Source: Grain SA

2.3.1 Seed size and coleoptile length

Cereal rye generally has a smaller seed size than wheat. Therefore, sowing depth should be adjusted according to this smaller seed size.

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

Seed size is usually measured by weighing 1000 grains (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. [45]

Because small seeds contain less starch reserves than larger seeds, they have less energy to get the seedling out of the ground and less energy to fight stresses such as disease, waterlogging or false breaks.

Small seed—for example, 1000-seed weight <30 g—should not be sown deep, and should only be sown where there is ideal moisture. Increase sowing rates by 10–15% to compensate for potentially low vigour. [46]

The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface (see Photo 8). Coleoptile length is an important characteristic to consider when planting a crop, especially in drier seasons when sowing deep to reach soil moisture.

44 H Hatting (2102) Factors affecting wheat seed germination. Grain South Africa, http://www.grainsa.co.za/factors-affecting-wheat-seed-germination

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

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

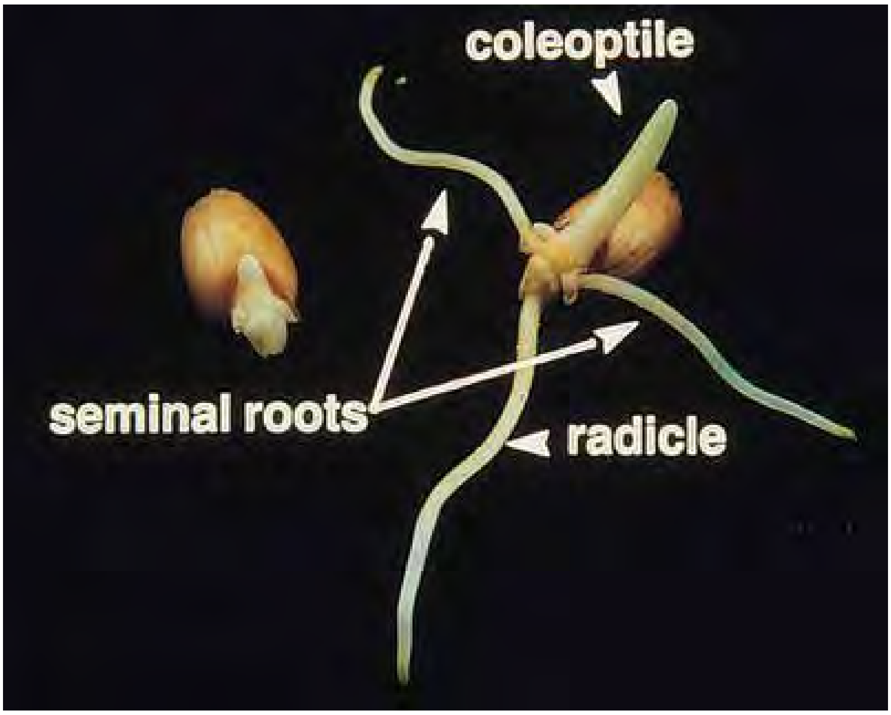


Photo 8: *The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface.*

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. If varieties with short coleoptiles are sown too deep, it can cause poor establishment because the shoot will emerge from the coleoptile underground and may not reach the soil surface.

Coleoptile length is influenced by several factors including variety, seed size, temperature and soil water and by 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, to see what affect it may have on coleoptile length. [47]

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. [48]

In rye, seed germination drops rapidly when seed is stored for longer than one year. [49]

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

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

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

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

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

Seeds lose vigour before they lose the ability to germinate. Therefore, seedlots with similar, high germination values can differ in their physiological age (the extent of deterioration) and so differ in seed vigour and the ability to perform. [50]

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; it requires laboratory testing. [51]

Request a copy of the germination and vigour analysis certificate for purchased seed from your supplier. For seed stored on-farm, you can send a sample to a laboratory for analysis (see Australian Seeds Authority website).

Although a laboratory seed test for germination should be carried out before seeding to calculate seeding rates, a simple on-farm test can be done in soil at harvest and during storage:

- Use a flat, shallow, seeding tray (about 5 cm deep). Place a sheet of newspaper on the base to cover drainage holes, and fill with clean sand, potting mix or freely draining soil. Ideally, the test should be done indoors at a temperature of ~20°C or lower.
- Alternatively, lay a well-rinsed plastic milk container on its side and cut a window in it, place unbleached paper towels or cotton wool in the container, and lay out the seeds. Moisten and place on a windowsill. Keep moist, and count the seeds as outlined below.
- Randomly count out 100 seeds—do not discard damaged ones—and sow 10 rows of 10 seeds at the correct seeding depth. This can be achieved by placing the seed on the smoothed soil surface and pushing in with a pencil marked to the required depth. Cover with a little more sand or soil and water gently.
- Keep soil moist but not wet, as overwatering will result in fungal growth and possible rotting.
- After 7–10 days, the majority of viable seeds will have emerged.
- Count only normal, healthy seedlings. If you count 78 normal vigorous seedlings, the germination percentage is 78%.
- Germination of 80% is considered acceptable for cereals.
- The results from a laboratory seed-germination test should be used for calculating seeding rates. [52]

Seed purity

Seed impurity can occur from contamination through harvest, storage and machinery. This measurement will be included in a seed purity certificate. Varieties that have been retained for multiple generations have an increased risk of seed impurity due to multiple chances for contamination events and build-up. Ensure that seed comes from clean, pure and even crops; seed-purity tests should be carried out. Growers

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

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

52 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

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. [53]

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.

The ideal storage conditions:

- 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. This 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 their activity and reducing damage. [54]

For more information, see Section 13: Storage.

VIDEOS

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

2.3.4 Safe rates of fertiliser sown with the seed

Most varieties of cereal rye do not require any additional fertiliser over requirements of other cereals. However, given its ability to produce winter feed very quickly, strong economic responses can be gained by supplying the crop with a good amount of starter fertiliser (e.g. >100 kg/ha of di-ammonium phosphate). Follow up with a topdressing of N (30–50 kg/ha) when the crop is at early tillering stages, perhaps three weeks after emergence. Additional fertiliser and lime can be applied according to a soil test. [55]

Crop species differ in tolerance to N fertiliser when applied with the seed at sowing. Research funded by Incitec Pivot Fertilisers has shown that the tolerance of crop species to ammonium fertilisers placed with the seed at sowing is related to fertiliser product (ammonia potential and osmotic potential), application rate, row spacing and equipment used (such as a disc or tyne), 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, adhere closely to the safe rate limits set for the crop species and the soil type. [56]

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

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

55 Wrightson seeds (2010) Forage Focus: Southern Green forage rye, http://www.pggwrightsonseeds.com.au/assets/FTP-Uploads/Forage_Focus/Cereals/FF_Southern-Green-Forage-Ryecorn.pdf

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

High rates of N fertiliser applied at planting in contact with, or close to, the seed may severely reduce seedling emergence. If a high rate of N is required, it should be applied pre-planting or applied at planting but not in contact with the seed (i.e. banded between and below sowing rows). Rates should be reduced by 50% for very sandy soil and increased by 30% for heavy-textured soils or if soil moisture conditions at planting are excellent. [57]

If the same fertiliser rate is used with different row spacings, then the amount distributed along each seeding row will increase as row spacing becomes wider. To avoid this increased fertiliser concentration in wide-row systems, the safe rate of in-furrow fertiliser decreases as row spacing increases (Table 7). Seedbed utilisation percentage is a term that has been developed to describe the effect of row spacing and opener type on seed-furrow fertiliser concentration, and thereby quantify safe fertiliser rates (Table 8). Higher seedbed utilisation can optimise crop grain-yield potential, as well as minimising fertiliser toxicity risk. [58] [59]

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

Soil texture	25-mm seed spread			50-mm seed spread		
Row spacing:	180 mm	229 mm	305 mm	180 mm	229 mm	305 mm
SBU:	14%	11%	8%	29%	22%	17%
Light (sandy loam)	20	15	11	40	30	22
Medium–heavy (loam–clay)	25	20	15	50	40	30

SBU, Seedbed utilisation = (width of seed row/row spacing) × 100.

Source: RW Rainbow and DV Slee (2004), The essential guide to no-till farming (South Australian No-Till Farmers Association), reproduced in GRDC Fertiliser Toxicity Fact Sheet

Table 8: *Urea rates (kg/ha) for wheat and barley at different levels of seedbed utilisation (SBU = width of seed row/row spacing × 100) and on different soil types, with good soil moisture.*

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

Source: Incitec Pivot Fertfact

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

57 QDAF (2102) Wheat —nutrition. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/nutrition

58 GRDC (2011) Care with fertiliser and seed placement. GRDC Fertiliser Toxicity Fact Sheet, May 2011, https://grdc.com.au/uploads/documents/GRDC_FertiliserToxicity_FS.pdf

59 J Laycock (2013) Seedbed utilisation. Fertfact—Guidelines for suggested maximum rates of fertiliser applied with the seed in winter crops. Incitec Pivot Fertilisers, http://farmercommunity.incitecpivotfertilisers.com.au/Guides%20and%20Publications/Agronomic%20Insights/Seed%20bed%20utilisation

Planting

Key messages

- Rye for grain is sown at the same time as wheat, oats or barley (April–June), although it is often sown first because rapid groundcover is normally desirable on the soils where it is sown.
- Target plant recommendations are 120–150 plants per m^2 for grazing and grain crops, or a seeding rate of ~60–70 kg per hectare. Larger populations are needed for green manure crops. [1]
- Seed should be drilled to about 2.0–2.5 cm deep in heavy soils, 3.5–4.5 cm in sandy soils. [2]
- Allow 15–18 cm between rows when seeds are drilled. [3]

3.1 Seed treatments

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

There are risks associated with using seed treatments. Some seed treatments can delay emergence by:

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

If there is a delay in emergence due to decreased vigour, it increases exposure to pre-emergent attack by pests and pathogens, or to soil crusting. This may lead to a failure to emerge. The risk of emergence failure increases when seed is sown too deeply or into a poorly prepared seedbed, especially for varieties with shorter coleoptiles. As the amount of some fungicides increases, the germination rate slows (Figure 1). [4]

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

2 Agriculture Victoria (2013) Growing cereal rye, Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

3 Plant Village. Rye: *Secale cereale*. Penn State Extension, https://www.plantvillage.org/en/topics/rye/diseases_and_pests_description_uses_propagation

4 NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/growth-and-development

MORE INFORMATION

PIRSA: Cereal seed treatments 2017

GRDC fact Sheet: Targeted nutrition at sowing

VIDEOS

WATCH: GCTV Extension files: Wheat sowing strategies

WATCH: GCTV Extension files: Early sowing opportunities

WATCH: Early sowing in the LRZ

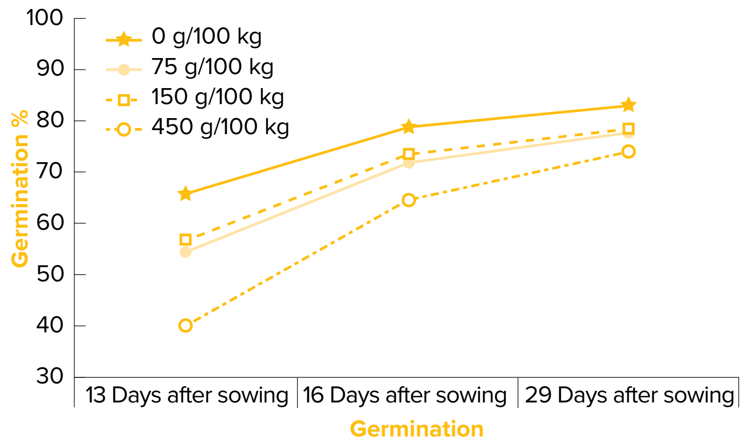


Figure 1: *Impact of seed-treatment fungicide on the rate of germination.* [5]

Source: based on P Cornish 1986

Product registrations change over time and may differ between states and between products containing the same active ingredient. Prior to use, it is critical to check the registration status on the current product label for the intended use pattern in your state.

3.1.1 Emergence problems

Factors other than seed treatments can cause poor seedling emergence, including deep sowing, surface crusting, use of short coleoptile varieties, suboptimal soil temperatures, and the pre-emergent herbicide 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 among varieties, some can tolerate deeper sowing than others. Coleoptile lengths also vary greatly from one batch of seed to another. Seed source is often more critical than variety in determining coleoptile length. Therefore, 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. [6]

3.1.2 Fertiliser at seeding

The amount of nitrogen (N) safely placed with the seed will vary depending on soil texture, amount of seedbed utilisation and moisture conditions. Higher rates of N can be safely applied with the seed if it is a polymerised form of urea, from which the N is released over several weeks. If soil moisture is marginal for germination, high rates of fertiliser should not be placed with the seed. Nitrogen 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. [7]

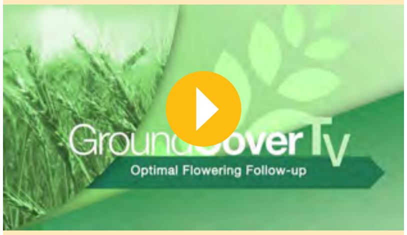
5 P Cornish (1986) Effects of a triadimefon–lindane seed treatment on the germination, seedling morphology and emergence of wheat. *Australian Journal of Experimental Agriculture* 26, 227–230, http://www.publish.csiro.au/an/EA9860227

6 H Wallwork H (2017) Cereal seed treatments 2016. PIRSA, http://www.pir.sa.gov.au/__data/assets/pdf_file/0005/237920/cerealseedtreat2017_web.pdf

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

VIDEOS

WATCH: GCTV15: Optimal flowering—follow up



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

MORE INFORMATION

GRDC Fact Sheet: Time of Sowing Factsheet—Southern Region

3.2 Time of sowing

Rye for grain is sown at the same time as wheat, oats or barley (April–June). Because rapid groundcover is usually required on the soils where rye is sown, it is often sown first.

If seasonal conditions are unfavourable for pasture growth in the Mallee, cereal rye is often sown dry during March for green feed, in which case the sowing rate should be increased to 80–100 kg per hectare to maximise fodder production. Graze when plants are 150 mm high and tillering. The later stages of growth are stemmy and unpalatable to stock. Cereal rye is generally not a suitable hay crop.

For the purposes of green manure, cereal rye can be sown in February or March or as late as August in high-rainfall areas. [8]

Best results are generally obtained from early-sown rye crops. If sufficient moisture is available, it may be sown in the last half of February for early green feed. [9]

3.3 Targeted plant population

Target plant numbers to account for differences in tillering capacity:

- A seed germination and viability test should be performed if you think there may be a problem, such as after a drought or late frost, or if seed is old.
- Check 1000-seed weight from each seedlot each year.
- Alter sowing rates to account for target population, seed size and germination. [10]

Plant population, determined by seeding rate and establishment percentage, can be an important determinant of tiller density and, at a later stage, head density. [11]

Target plant densities should reflect the tillering capacity of the variety. Low-tillering varieties should be sown at higher plant densities than high-tillering varieties to achieve target tiller numbers.

Target tiller numbers relate to the number of tillers that can be sustained to produce optimum yields. This often relates to rainfall, e.g. the target tiller number for 500-mm rainfall zone is ~500 tillers per m^2.

Seed size influences plant density, with large seeds requiring a higher sowing rate than smaller seeds to target the same population. The 1000-seed weight is a measure of seed size and should be determined for each seedlot, because results vary depending on the age of seed and the conditions under which it has been grown. [12]

Despite the crop's 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

8 Agriculture Victoria (2013) Growing cereal rye. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

9 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

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

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

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

- soil fertility
- soil type
- soil moisture and seasonal outlook
- weed-seed burden—higher sowing rates for increased plant competition, e.g. if combatting herbicide-resistant ryegrass populations. [13]

IN FOCUS

Effect of seeding rate and planting arrangement on rye cover crop and weed growth.

Weed growth in winter cover crops in warm climates may contribute to weed-management costs in subsequent crops. A two-year experiment was conducted on an organic vegetable farm in the USA to determine the impact of seeding rate and planting arrangement on rye cover crop growth and weed suppression. Each year, rye was planted at three rates (90, 180, and 270 kg/ha) and two planting arrangements (one-way *v.* grid pattern). Averaged across years, rye population densities were 322, 572, and 857 plants/m^2 at the 90, 180, and 270 kg/ha seeding rates, respectively. Early-season rye groundcover increased with seeding rate and was higher in the grid than the one-way arrangement in year 1; however, rye groundcover was not affected by rate and was higher in the one-way arrangement in year 2. Aboveground dry matter (DM) of rye increased with seeding rate at the first two harvests but not at the final one. Planting arrangement did not affect rye aboveground DM in year 1, but rye DM was higher in the grid pattern at the first and final harvests in Year 2. Weed emergence was not affected by seeding rate or planting arrangement. Weed biomass decreased with increased seeding rate and was lower in the grid than in the one-way arrangement in year 2. A grid planting pattern provided no consistent benefit but planting rye at higher seeding rates maximises early season rye DM production and minimises weed growth. [14]

TOPCROP Victoria investigated sowing rates for wheat to achieve target plant densities in large-scale paddock demonstrations during the 2000 season. TOPCROP farmer groups established 30 sites across Victoria comparing 75%, 100%, 150% and 200% of the district practice for sowing rate. Findings indicated that poor seeder calibration and a lack of understanding of the influence of grain size led to target plant densities not being reached. This highlights the need for sowing recommendations to be based on target plant densities rather than sowing rates. [15]

13 NSW DPI District Agronomists (2007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/growth-and-development

14 NS Boyd, EB Brennan, RF Smith, R Yokota (2009) Effect of seeding rate and planting arrangement on rye cover crop and weed growth. *Agronomy Journal* 101, 47–51.

15 A Johnson, M Evans, K Wansink (2001) Challenging sowing rates for wheat to achieve target plant densities, 10th Australian Agronomy Conference, Australian Society of Agronomy/The Regional Institute Ltd, http://agronomyaustraliaproceedings.org/images/sampledata/2001/p/10/johnson.pdf

3.4 Calculating seed requirements

Farmer observations suggest that sowing rye at low rates may make the crop easier to harvest. [16] Cereal rye is tall and the bulky straw makes harvest slow due to the large volume going through the harvester. [17]

Rate of sowing can vary from 40 to 135 kg/ha, with higher rates being used when seed is broadcast for green feed. The usual sowing rate when drilled is 60–70 kg/ha. [18]

Sowing rates vary with seed size, target plant population and establishment percentage. Growers should target 120–150 plants per m^2 for grazing and grain crops. Higher population densities are needed for green manure crops. Comparative seed rates for grazing and grain crops are 60–70 kg/ha and for green manure 80–100 kg/ha. [19]

IN FOCUS

Agronomic requirements for a semi-dwarf rye variety: phosphorus and sowing rate.

Cereal rye has a valuable role in controlling soil erosion on sand ridges and related light soil types. Breeding work at the Waite Agricultural Research Institute produced semi-dwarf, high-yielding lines and this study was designed to determine the rates of P and sowing required to realise their greater yield potential compared with SA Commercial.

A trial was sown on 14 June 1988 at Lameroo to compare the responses to sowing rate of a semi-dwarf rye variety (B88) and SA Commercial. The June–November rainfall was 210 mm, 10% below average. A split-plot design was used with varieties as the main treatments and six sowing rates (25, 40, 55, 70, 85, 100 kg/ha) as subplots. The trial received 12 kg P and 5 kg N/ha applied as mono-ammonium phosphate.

Sowing rate had no significant effect on yield in 1987 but a significant variety × sowing rate response occurred in the 1988 trial (Figure 2). B88 showed little response to sowing rate but the yield of SA Commercial decreased with increasing sowing rate. More tillers of SA Commercial died at the higher sowing rates and it lodged late in the season. The reduction in yield of this variety at high sowing rates was associated with a greater reduction in grain weight. This was possibly due to the combined effects of lodging and a dry spring during the grain-filling phase. The study showed that the P rates and sowing rates used for rye are unlikely to limit the yield potential of the semi-dwarf lines. [20]

16 NRSA (2014) Managing land classes for better feed utilisation—producer case study. Natural Resources SA, http://www.naturalresources.sa.gov.au/files/e7e04254-1bae-4763-9400-a38700980519/managing-land-classes-for-better-feed-utilisation-walsh-case-study-gen.pdf

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

18 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

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

20 G Dean, G McDonald (1989) Agronomic requirements of a new semi-dwarf variety 1: Phosphorus and sowing rate. 5th Australian Agronomy Conference, http://www.regional.org.au/au/asa/1989/contributed/plant-nutrition/p-03.htm

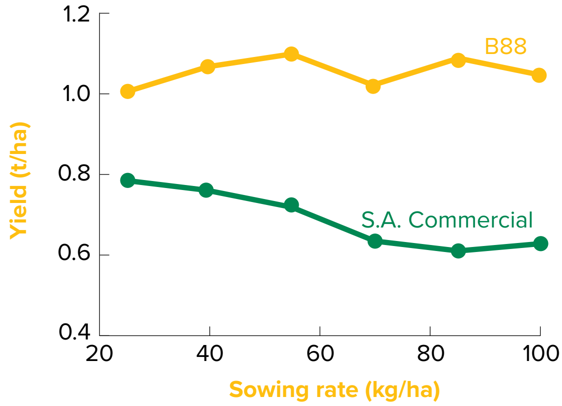


Figure 2: *Grain yield response of the semi-dwarf B88 and SA Commercial cereal rye to sowing rate.*

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

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

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

- target plant density
- germination percentage
- seed size
- establishment, usually 80%, unless sowing into adverse conditions.

To calculate 1000-seed weight:

- count out 200 seeds
- weigh to accuracy of at least 0.1 g
- multiply weight (g) by 5. [21]

21 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2014. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

Example

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

= Your seedling rate 68 kg/ha

Your calculation

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

= Your seedling rate ______ kg/ha

Figure 3: *Seeding rate calculator.*

Source: NSW DPI Winter crop variety guide

3.5 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. [22] Also, it is important to separate the seed from any pre-emergent herbicides used. [23]

Sowing depth for cereal rye should not exceed 5 cm. Bevy rye should be sown at depths not exceeding 2.0–2.5 cm in heavy soils and 3.5–4.5 cm in sands. [24]

Research in Canada has shown that rye sown at a 2.5 cm depth has twice the emergence of that sown at ~5 cm and that shallow-seeded rye had greater winter hardiness. [25]

Rye has four primary roots that originate from the seed and it can send out roots and tillers from the second, third and fourth node. This extensive root system within the first 30 cm of soil is more developed than in other cereals. This makes rye useful for sowing over eroded or disturbed sites, where depth is hard to control, and makes the plant more drought-resistant. [26]

Seed size influences coleoptile length, which is sensitive to sowing depth. Sowing depth influences the rate of emergence and the emergence percentage. 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.

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

23 S Kleemann, J Desbiolles, G Gill, C Preston (2015) Seeding systems and pre emergence herbicides Coonabarabran. GRDC Update Papers, Feb. 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Seeding-systems-and-pre-emergence-herbicides-Coonabarabran

24 Agriculture Victoria (2013) Growing cereal rye. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

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

26 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Leibe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

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. [27]

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

3.6 Sowing equipment

Seeder calibration is important for precise seed placement and seeders need to be checked regularly during sowing (Photo 1).

Most growers in the Southern Region use either a tyne system with knife-points and press-wheels 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.

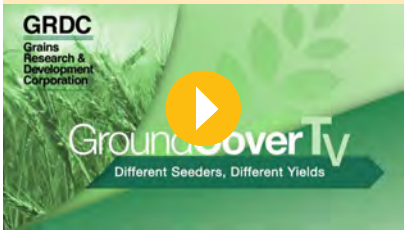
Photo 1: *Seeder calibration is important for precise seed placement, and seeders need to be checked regularly during sowing.*

Photo: Rohan Rainbow

VIDEOS

WATCH: SFS seeder trial.

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



27 NSW DPI Agronomists (2007) Wheat growth and development. PROCROP Series. NSW Department of Primary Industries 2007, http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/winter-crops/wheat,-barley-and-other-winter-cereals/growth-and-development

Plant growth and physiology

Key messages

- Some cereal rye seeds are thought to be able to remain viable and dormant in soils for around five years. [1]
- Rye can establish in very cool weather. It will germinate at temperatures as low as ~1°C. Vegetative growth requires at least 3°C. [2]
- Seeds germinate from autumn to spring with a flush in autumn at temperatures of 1°–5°C. [3]
- Rye needs a cumulative soil temperature from the time of planting of 90°C for field emergence, provided sufficient water is present. [4]
- Cereal rye is a long-day plant; that is, it requires increasing daylength to induce flowering. [5]
- Cereal rye has a more extensive root system in the top 30 cm than wheat and oats. This more developed root system increases soil stabilisation and allows the plant to explore more of the topsoil profile, increasing the plants tolerance to dry conditions. [6]

4.1 Characteristics of the cereal rye plant

Plant parts of cereal rye are described in Key characteristics:

- inflorescence a dense cylindrical spike and not enclosed in the leaf sheath
- spikelets subtended by two glumes, solitary at each node of the rachis, not digitate, sessile, erect with two (rarely three) bisexual florets, breaks above the more or less persistent glumes
- two lemmas, awned, five-ribbed. [7]

1 WL Stump, P Westra (2000) The seedbank dynamics of feral rye *Secale cereale* 1. *Weed Technology*, 14, 7–14.

2 SARE (2007) Cereal rye. Managing cover crops profitably. 3rd edn. Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

3 Rye. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

4 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

5 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

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

7 Rye. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

Table 1: *Characteristics of the cereal rye plant.*

Plant part	Description
Cotyledons	One
Leaves	Emerging leaf rolled in the bud Blade: rough to touch, flat. Hairless. 75–300 mm long, 10–20 mm wide Ligule: membranous rim, 1 mm long, flat on top Auricles: small Sheath: hairless, rolled and overlapping, prominent veins Collar: prominent and lighter, hairless
Stem	Erect, slender, 200–1500 mm tall; hairless or hairy below the seed head; usually has a waxy bloom; tillers vigorously with usually fewer than 10 stems arising from the base
Flower head	Bearded, dense cylindrical spike; 70–150 mm long; erect initially and drooping with age; awned (Figure 1)

Photo 1: *Comparison of flower heads between (A) bread wheat, (B) cereal rye and (C) triticale.*

Source: Palomar College, CA, USA

Flowers	Spikelets: no stalk, flattened; single and overlapping in a row on opposite sides and pressed against a zigzag stem; strongly attached to the stem; two fertile florets per spikelet Florets: bisexual. Glumes: two the same size and shape, awl-shaped, 7–10 mm long, one rib, keeled, flattened, rough to touch Palea: 12–15 mm long, narrow, no awns, two lobes, two keels Lemmas: two; stick out from the glumes; oblong to narrowly egg shaped; 12–15 mm long; stiff; five ribs; flattened; hairy or finely toothed on the keel and edges; keel tapers to a long straight awn ~20 mm long

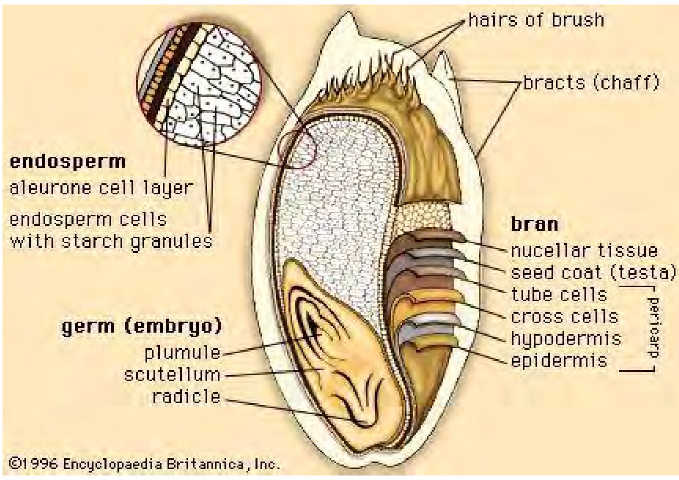
Seeds	Light to dark brown; oblong to oval or wedge shaped; 5–7 mm long and 2–3 mm wide; almost circular in cross-section; surface grooved, wrinkled and hairless; easily rubbed from the husks (Figure 2)
	
Roots	Many and fibrous

Figure 1: *Cross-section of cereal rye seed.*

Source: Encyclopaedia Britannica

Source: HerbiGuide Pty Ltd

4.2 Germination and emergence issues

4.2.1 Dormancy

Cereal rye seeds are thought to be able to remain viable and dormant in soils for around five years.

IN FOCUS

The seedbank dynamics of volunteer rye

Buried feral rye seeds were rapidly depleted in soil in the first year due to *in situ* germination. Less than 1% of the viable seeds persisted after 45 months of burial. After five years, a small number of seedlings still emerged; however, soil seedbank decline was rapid when seed production was prevented. A low level of induced dormancy was detected and may explain the small populations of feral rye that persisted. Seed and seedling population shifts were large over a five-year period and were related to environmental conditions. Tillage or chemical control of feral rye in the fallow period reduced populations compared with the untreated weedy check. Mouldboard ploughing provided the greatest control of feral rye compared with shallow tillage and chemical fallow. Feral rye seedbank populations rebounded following a wet final year of the study. These results help to explain feral rye persistence in a wheat–fallow agroecosystem by the persistence of a small portion of the seedbank and by large seed inputs into the system during environmentally favorable years. Feral rye reduced wheat yield as much as 92% and represented up to 73% contamination in harvested wheat. [8]

8 WL Stump, P Westra (2000) The seedbank dynamics of feral rye *Secale cereale* 1. *Weed Technology* 14, 7–14.

4.2.2 Germination

Seeds germinate from autumn to spring with a flush in autumn. [9] Minimal temperatures for germinating cereal rye have been variously given as between 1°C and 5°C. [10] Rye prefers light loams or sandy soils and will germinate even in fairly dry soil. [11]

Rye sown at 2.5 cm depth has twice the emergence of rye sown at ~5 cm, and shallow-seeded rye has greater winter hardiness. [12]

With regard to environmental stress factors for seed germination and seedling growth, cereal rye was found to be exceptionally resistant to a wide variety of ordinarily harmful conditions:

- Germination is anaerobic and proceeds well in the presence of carbon monoxide, nitrous oxide and hydrogen.
- Rye grains germinate readily at constant low temperatures (e.g. 5°C) and some can germinate on a cycle of 16 hours at −30°C and 8 hours at 20°C for periods of 7 days.
- Liquid nitrogen temperatures can also be endured by dry seeds.
- In seawater and similar media, 100% germination can be achieved in 10 days. [13]

Rye has been found more tolerant of saline conditions during germination than wheat and some triticale varieties. [14]

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.

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. [15] Also, it is important to separate the seed from any pre-emergent herbicides used. [16]

When shallow seeding, the previous crop's residue will have a greater tendency to interfere with good seed–soil contact. Even spreading of the previous crop residue is essential for quick emergence. Ensure that seed–soil contact occurs. [17] Aim for a seeding depth similar to wheat or barley.

For other germinating plants, rye residue that remains at the soil surface can modify the physical and chemical environment during seed germination and plant growth. [18]

9 Rye. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

10 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

11 SARE (2007) Cereal rye. Managing cover crops profitably. 3rd edn. Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

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

13 SM Siegal, LA Halpern, C Giumarro (1964) Germination and seedling growth of winter rye in deuterium oxide. *Nature* 201, 1244–1245, http://www.nature.com/nature/journal/v201/n4925/abs/2011244a0.html

14 UR Bishnoi, DK Pancholy (1980) Comparative salt tolerance in triticale, wheat and rye during germination. *Plant and Soil*, 55, 491–493.

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

16 S Kleemann, J Desbiolles, G Gill, C Preston (2015) Seeding systems and pre emergence herbicides Coonabarabran. GRDC Update Papers, Feb. 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Seeding-systems-and-pre-emergence-herbicides-Coonabarabran

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

18 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Corn agronomy: Rye. University of Wisconsin Extension, http://corn.agronomy.wisc.edu/Crops/Rye.aspx

4.2.3 Emergence

Rye needs a cumulative soil temperature since planting of 90°C for field emergence, provided sufficient water is present. [19] For the first two weeks after germination, the stems are thin and delicate (Photo 2). [20]

Photo 2: *Emergence of rye cover crop at 11 days after planting.*

Source: Virginia Association for Biological Farming

Sowing depth influences the rate and percentage of emergence. Deeper seed placement slows emergence. Seedlings emerging from greater depth are also weaker and more prone to seedling diseases, and they tiller poorly.

If deep sowing, it is important to avoid smaller sized seed because smaller seeds have shorter coleoptiles, which may stop growing before reaching the soil surface. The first leaf will then emerge from the coleoptile while still below the soil surface. Because it is not adapted to pushing through soil (does not know which way is up), the leaf usually buckles and crumples, failing to emerge and eventually dying. [21]

Rye has been found to be slightly less salt-tolerant during plant emergence than during subsequent stages of growth. [22]

4.3 Environmental effects on plant growth and physiology

4.3.1 Photoperiod and temperature

Cereal rye is a long-day plant; that is, it requires increasing day length to induce flowering. It has a shorter growth period than other winter and spring cereals that also differ considerably in vernalisation period (i.e. induction of a plant's flowering process by exposure to prolonged cold). Winter types of rye require 40–60 days of cold temperatures, whereas the spring types require only 10–12 days to shift into the reproductive stage. [23]

19 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

20 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

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

22 LE Francois, TJ Donovan, K Lorenz EV Maas (1989) Salinity effects on rye grain yield, quality, vegetative growth, and emergence. Agronomy Journal, 81(5), 707-712.

23 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

Rye achieves more rapid rates of pre-anthesis dry matter accumulation than other cereals, irrespective of whether grown at high (20°–15°C) or low (10°–7°C) day–night temperatures. Tiller number and leaf area per plant are greater for rye, especially at low temperatures, than triticale and wheat. [24]

Effect on frost tolerance

One study suggests that photoperiod and temperature during cereal rye growth can influence frost tolerance.

IN FOCUS

The interrelationship of growth and frost tolerance in winter rye

The reduction in growth of winter cereals that occurs in the autumn is thought to be required for the development of frost resistance. In the present study, the interrelationship of freezing tolerance and growth was examined by raising winter rye (*Secale cereale* cv. Puma) plants at 20°–16°C (day–night) and at 5°–3°C under daylengths 8, 16 and 24 h to vary growth rates and frost tolerance. Temperature and irradiance were quantified as thermal time, photothermal time and photosynthetic photon flux and statistically analysed to determine their effects on growth and frost tolerance of rye shoots. At low temperature, both growth and frost tolerance were markedly influenced by daylength and irradiance. Plants grown at 5°–3°C with a short daylength accumulated shoot dry weight and increased frost tolerance at a greater rate per unit photothermal time or photon flux than plants grown at longer daylengths. Moreover, 5°–3°C plants grown with a 16-h daylength grew more slowly and were less frost-tolerant than plants grown with a 24-h daylength. It was concluded that the interrelationship between growth and frost tolerance is quantitative. Frost tolerance is induced only by low temperature, but the development of frost tolerance is dependent on both irradiance, which affects the amount of photoassimilate available, and daylength, which may affect the partitioning of photoassimilates between growth and frost tolerance. [25]

4.3.2 Salinity

Cereal rye is thought to be relatively tolerant on saline soils, similar to barley, but will be affected in highly saline soils (electrical conductivity of the soil saturated paste extract (ECe) 8–16 dS/m). [26]

Relative grain yield of two rye cultivars in a field experiment in Canada was unaffected up to a soil salinity (EC) of 11.4 dS/m. Each unit increase in EC above 11.4 dS/m reduced yield by 10.8%. These results place rye in the salt-tolerant category. Yield reduction was attributed primarily to reduced spike weight and individual seed weight rather than spike number. Bread quality decreased slightly with increasing levels of salinity. Straw yield was more sensitive to salinity than was grain yield. Rye was found to be slightly less salt tolerant during plant emergence than during subsequent stages of growth. [27]

24 M Winzeler, DE McCullough, LA Hunt (1989) Leaf gas exchange and plant growth of winter rye, triticale and wheat under contrasting temperature regimes. *Crop Science* 29, 1256–1260.

25 M Griffith, HC McIntyre (1993) The interrelationship of growth and frost tolerance in winter rye. *Physiologia Plantarum* 87, 335–344.

26 C Henschke, T Herrman (2007) Testing for soil and water salinity. Factsheet No: 66/00. Primary Industries and Resources SA, http://www.saltlandgenie.org.au/_literature_81273/pp_-_testing_for_soil_and_water_salinity

27 LE Francois, TJ Donovan, K Lorenz EV Maas (1989) Salinity effects on rye grain yield, quality, vegetative growth, and emergence. *Agronomy Journal* 81, 707–712.

4.3.3 Soil water

Early studies into rye growth in Australia found exposure to conditions of low water resulted in yield reductions. This was due to depressed assimilation of nitrogen into leaves and reduced intake of phosphorus. [28]

Despite this, cereal rye is thought to be one of the most drought-tolerant cereals.

IN FOCUS

Shoot and root dry weight and soil water in wheat, triticale and rye

Dry matter distribution between the shoots and root was evaluated for three cereal cultivars, one each of wheat (*Triticum aestivum*), triticale (× *Triticosecale*) and rye (*Secale cereale*). Evaluations were made both indoors and outdoors (43°39'N 80°25' W) at four growth stages. Volumetric soil water content beneath the three species was also measured in the field. There were significant differences among the three species in total plant dry weight indoors and outdoors. Rye consistently had the greatest total plant dry mass, although total root dry weight was not greater than for the other species in many comparisons, especially before anthesis. However, rye root growth surpassed the others after anthesis, and root dry weight was greater at final harvest. Triticale and rye had greater shoot:root ratios than wheat at the later growth stages. Although there were no consistent differences among species in root dry weight distribution at different soil depths, rye had a relatively larger proportion of root dry weight in the upper soil layer than the other species. Species effects on soil water content were significant at depths of 15–45 and 45–90 cm during a drought period. Water content in the 45–90-cm layer was lower for triticale than for wheat and rye. [29]

For more information, see Section 14: Environmental Issues

4.4 Plant growth stages

The developmental cycle of rye can be divided into 12 stages. During stage 1, the growing point is not differentiated. In stage 2, the primordia of stems, nodes, and internodes are formed in the growing point. Rye, usually planted in autumn and under moderate climatic conditions, enters winter during stage 2.

In stage 3, the growing point differentiates into further segments, which are primordia of spikelets. During this period, nitrogen supply has a positive effect on the formation of a large number of spikelets, which leads to the subsequent formation of longer spikes with a greater number of flowers and grains.

A further differentiation of growing points takes place during stages 3 and 4, when flower primordia are formed. This process takes place in early spring. During the formation of spikelet primordia in the upper part of the spike, flowers are formed in the middle portion.

The plant then enters stage 5 of organogenesis. Under conditions of long days and poor nitrogen supply, this process is relatively fast.

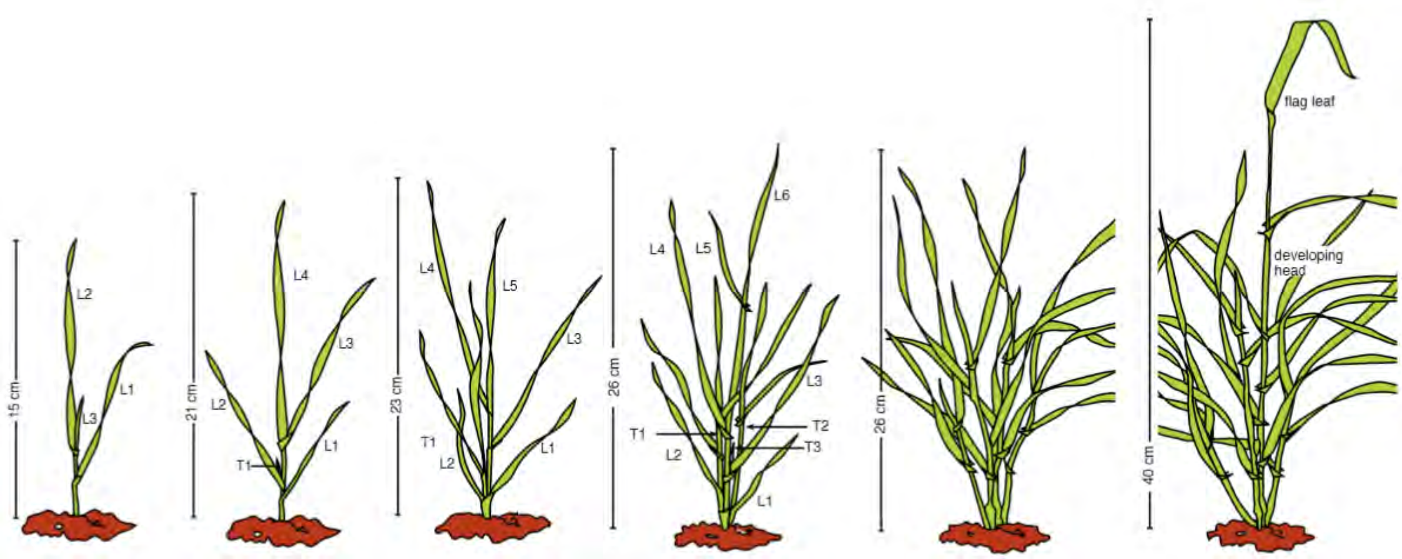
28 RF Williams, RE Shapter (1955) A comparative study of growth and nutrition in barley and rye as affected by low-water treatment. *Australian Journal of Biological Sciences* 8, 435–466.

29 Q Sheng, LA Hunt (1991) Shoot and root dry weight and soil water in wheat, triticale and rye. *Canadian Journal of Plant Science* 71, 41–49.

Meiotic division of pollen mother cells and the formation of tetrads, the embryo sac, and the egg take place during stages 6 and 7 of organogenesis. Stage 7 is characterised by extensive elongation growth during which pronounced elongation of shoot internodes takes place.

In stage 8, the plants ear and subsequently flower. Fertilisation and maturation of caryopses and plant then follow in the remaining four stages of development. [30]

The growth cycle of cereals including rye can also be described by using systems such as the Zadoks scale (Figure 2).



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 expand fully	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 5 leaves are 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 developing 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 main shoot or stem (Z16) Main shoot and three tillers (Z23)	First node formed at base of main tiller (Z31)	Z35–Z45

Figure 2: *Growth stages of cereal crops, including cereal rye.*

Source: NSW DPI

4.4.1 Roots

Cereal rye has four primary roots that originate from the seed and can send out roots and tillers from the second, third and fourth node. It has a more extensive root system in the top 30 cm than both wheat and oats. This more developed root system increases soil stabilisation and allows the plant to explore more of the topsoil profile,

30 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. Crc Press

increasing the plant's tolerance to dry conditions (Photo 3). Cereal rye roots are also able to growth through compacted soil (Photo 4). Rye can withstand sowing over eroded or disturbed sites where depth is hard to control. [31] [32]

Photo 3: *Dense root structure of cereal rye.*

Source: Iowa Farmer Today

31 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Leibe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

32 P Matthews, D McCaffery, L Jenkins (2015) (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

Photo 4: *Roots of cereal rye growing through a compacted layer of soil.*

Source: Healthy Soils Initiative

Rye has no taproot, but its quick-growing, fibrous root system can take up and hold as much as 45 kg nitrogen per hectare, but typically 12–23 kg. [33] Cereal rye roots can grow to over 1 m deep. This helps to recycle nutrients as well and building organic matter in the soil (Photo 5). [34]

Photo 5: *Deep growth of cereal rye roots.*

Source: Farm Progress

MORE INFORMATION

Research paper: Soil conditions and cereal root system architecture: review and considerations for linking Darwin and Weaver

33 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Leibe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

34 L Betts (2012) Rye crop calendar. Wallaces Farmer, http://farmprogress.com/story-2012-rye-cover-crop-calendar-14-94095

4.4.2 Plant development: photosynthesis and maturation

With the beginning of shooting, the reduction of tiller numbers starts. This is reinforced by nutrients, especially nitrogen (N) deficiency and/or drought. Overall, rye should not have to reduce more than 50% of the preformed tillers.

The flag leaf is smaller and less important in photosynthesis. Rye has the longest stems of all cultivated small grains, and these provide most of the photosynthetic area. During grain formation, stems with sheaths account for 60–80% of the total plant area. At grain-set, leaf blades provide 15-20% of the photosynthetic area, which is much lower than for maize, wheat and oats. Stems and sheaths have lower rates of photosynthesis and assimilate export than leaves. The most important periods of yield formation are flowering and grain-filling. Successful pollination depends on sufficient spreading of husks. Cold and rainy weather at flowering hamper the opening of husks, and thus the pollen distribution.

The maturation date of rye varies according to soil moisture, but vegetative growth stops once reproduction begins. In general, rye matures earlier than oats. The growth period, or time from sowing to harvest, is ~295 days in rye. The vegetation period lasts ~120–150 days.

At seedset, leaf blades provide 15–20% of the photosynthetic area. Stems and sheaths have lower rates of photosynthesis and export of assimilates than leaves. For rye, the photosynthetic area decreases rapidly after seedset and does not achieve a plateau near the maximum as seen with other grains. Its grain formation occurs under favourable physiological conditions for yielding. [35]

4.4.3 Vegetative behaviour

Field and pot investigations of the vegetative and early reproductive growth of a winter wheat cultivar and a winter rye cultivar over three seasons showed that higher and earlier forage yields of rye are due to a combination of factors, notably more rapid rates of germination, crop emergence, leaf appearance and leaf expansion, coupled with higher leaf area ratios. Studies of net assimilation rate found no evidence that the photosynthetic apparatus of rye plants is better adapted than wheat to the low temperature and light conditions of winter and early spring. However, the earlier initiation of rye stem extension was associated with significant increases in net assimilation rate, which compensated for reductions in the leaf area ratio. [36]

Rye tillers grow profusely, and individual plants can easily be split into several clones. Genotypes can differ in cloning ability. The production of tillers can be stimulated by cutting back the plants, which helps to retard the development of spikes. Cool, moist and short-day conditions increase the tillering capacity. Continuous light prevents jointing.

Earlier than 280 degree-days after field emergence, the four-leaf phase is reached and tillering starts. Once a shoot has formed six leaves and vernalisation is sufficient, the formation of spikelets begins. [37]

Rye has an erect, slender stem topped with a curved spike 7–15 cm in length. The head is made up of individual spikelets each with two florets, which produce one or two kernels. The spikelets are arranged alternately along the length of the head. The leaves of the plant grow from nodes on the stem and are lance-like blades, blue-green in color. Rye can reach up to 3 m in height. It is grown as an annual (spring rye) or biennial (winter rye). [38] However, the vast bulk of cereal rye grown in Australia is spring rye.

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35 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

36 RKM Hay, MKA Al-Ani (2009) The physiology of forage rye (*Secale cereale*). *The Journal of Agricultural Science* 101, pp. 63–70. doi: 10.1017/S0021859600036376.

37 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

38 PlantVillage. Rye: *Secale cereale*. Penn State Extension, https://www.plantvillage.org/en/topics/rye/diseases_and_pests_description_uses_propagation

Rates of dry matter accumulation early in the growing season are significantly greater for rye crops than for triticale and wheat. [39]

Depending on the cultivar and the growing conditions, 53–58% of total grain yield in cereal rye is produced by lateral shoots,. [40]

Winter rye generally overwinters in the tillering stage. Winter temperatures near freezing satisfy the vernalisation requirement and allow the plants to initiate reproductive development in the following spring. Rye varieties are long-day plants, but they do not have an absolute requirement for a specific daylength.

Rye is cross-pollinated, and relies on wind-borne pollen. The florets remain open for some time, but if conditions are not favorable for cross-pollination, rye spikes may have several empty florets. The inflorescence is a spike with one sessile spikelet per rachis node. Spikelet initiation begins in the middle of the spike and proceeds toward the tip and base. Only the two basal florets in each spikelet produce seed. Spring rye does not require vernalisation to induce flowering. [41]

4.4.4 Flowering and grain formation

Cereal rye flowers around August in southern Australia and from July to October in Western Australia. [42]

After flowering, the grain begins to form. As the grain develops, it goes through a clear liquid phase, prior to the commencement of starch deposition. The grain then enters the milky stages, described as early, medium and late milk. This is followed by soft and hard dough stages (Photo 6), and eventually leading to dry grain suitable for grain harvesting (Photo 7).

Photo 6: *Cereal grain (left) and plant (right) at the soft dough stage.*

Source: Agriculture Victoria

39 D McCullough, L Hunt (1993) Mature tissue and crop canopy respiratory characteristics of rye, triticale and wheat. *Annals of Botany* 72, 269–282.

40 K Hakala, K Pahkala (2003) Comparison of central and northern European winter rye cultivars grown at high latitudes. *The Journal of Agricultural Science* 141, 169–178.

41 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (19990) Alternative field crops manual: Rye. University of Wisconsin Extension, https://hort.purdue.edu/newcrop/afcm/rye.html

42 Rye. HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

Photo 7: *Cereal rye grain.*

Source: Atlas of Living Australia

As the plant reaches maturity, sugars in the stems and leaves are translocated to the grain and converted to starch. These changes are associated with changes in colour from an all-green plant in the vegetative stages to an all-yellow plant in the fully mature plant at the hard-grain stage (Photo 8).

Photo 8: *Rye ripening.*

Source: PlantVillage

Research to date indicates that although yield does increase substantially with crop maturity, there is generally a decrease in energy and protein and an increase in fibre levels. The drop in nutritive value is greater in rye and oats than in other cereals.

Nutrition and fertiliser

Key messages

- Cereal rye has an extensive root system and is able to take up nutrients efficiently. Rye is generally more efficient at taking up nutrients than wheat, barley or oats.
- Only rarely are strong symptoms of nutrient deficiency shown in rye crops. If symptoms are present, they are likely to be similar to those in wheat. [1]
- Rye can be planted on land that is not sufficiently fertile for other cereals such as wheat.
- Rye can easily be over-fertilised, and harvesting may be very difficult if the rye lodges from too much nitrogen (N). [2]
- Rye has no taproot, bit its quick-growing, fibrous root system can take up and store as much as 45 kg N per ha, with 12–23 kg more typical. [3]
- Low N and potassium (K) can cause plant stress in rye. [4]
- Rye can cycle K from deeper in the soil profile for use by future crops. [5]

5.1 Soil nutrient balance

According to long-term trials in the USA, cover crops on average can reduce N loading by 28% and phosphorus (P) loading by 50%. Since 2008, 46 site-years have been conducted, with farmers reporting that in 42 of 46 site-years, properly managed cover crops had little or no negative effect on maize and soybean yield (and actually increased soybean yield in 4 site-years). [6]

Rye should be fertilised when grown for pasture or as a cover crop. Early application of N and P increases early growth, which improves winter groundcover. A spring topdressing with N is desirable where rye is pastured. Heavy N applications promote lodging in rye grown for grain. A moderate rate of manure is a good general fertiliser. [7]

5.1.1 Benefits of rye to soil health

Trials in poor-quality soil at West Wubin in Western Australia have found that cropping cereal rye for three years increased soil organic carbon (SOC). SOC concentration increased in the topsoil by 27.8% in 2013 and 16.7% in 2014. This represents a total improvement of 47% since 2012 (Figure 1). However, there was little difference in SOC over the whole depth to 60 cm. [8]

1 M Wurst, R Brennan (2007) Winter cereal nutrition—the Ute Guide. GRDC, https://grdc.com.au/Resources/Publications/2007/05/Winter-Cereal-Nutrition-the-Ute-Guide

2 UVM Extension Crops & Soils Team (2011) Cereal rye. Northern Grain Growers Association, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

3 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Leibe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf ‘

4 RH Schlegel (2013). Rye: genetics, breeding, and cultivation. CRC Press.

5 Manure $ense (2009) Cereal rye: manure and livestock's new best friend. Midwest Cover Crops Council, http://mccc.msu.edu/wp-content/uploads/2016/09/MI_2009_CerealRyeManure.pdf

6 S Gailans (2015) Winter cereal rye cover crop effect on cash crop yield: results from long-term, on-farm research. Synergy in Science, https://scisoc.confex.com/scisoc/2015am/webprogram/Paper91725.html

7 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Alternative field crops manual: Rye. University of Wisconsin Extension, https://hort.purdue.edu/newcrop/afcm/rye.html

8 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

MORE INFORMATION

Liebe Group: Growing cereal rye to increase carbon and prevent wind erosion

MSF: Karoonda break crops trails—soil biology and rhizoctonia disease

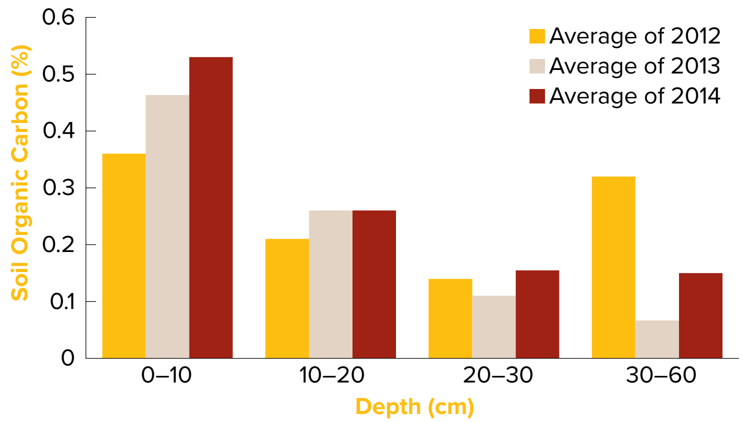


Figure 1: *Average soil organic carbon percentage 2012–14, sampled from four depths.*

Source: Liebe Group

In a trial at Karoonda, South Australia, N-mineralisation potentials were higher in soils after mustard, pasture and cereal rye than after wheat. Microbial activity was higher in the cereal rye soils than other crops mainly due to the abundant root growth and associated belowground carbon inputs. Microbial biomass levels after cereal rye were higher than after wheat, indicating the greater potential for immobilisation (temporary tie-up) of nutrients caused by wheat. These differences in microbial activity and nutrient mineralisation are due to the variation in quantity and quality of crop residues, reflected in the amount of mineral N in soil profile at sowing, e.g. higher mineral N levels after cereal rye than after wheat (Figure 2). [9]

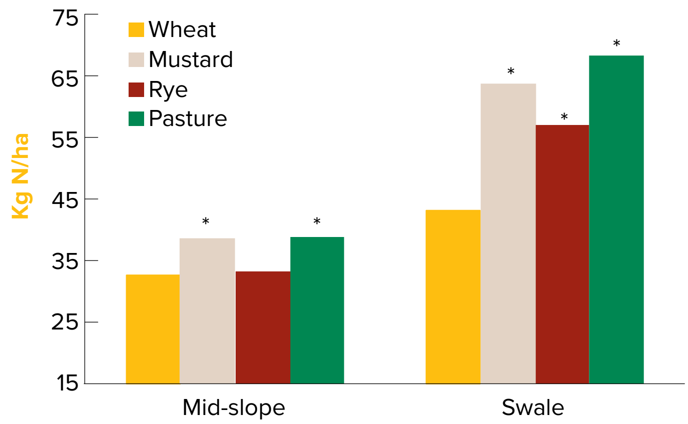


Figure 2: *Effect of rotation crops in 2009 on nitrogen supply potential in the surface 10 cm soil prior to sowing of a wheat crop in 2010. *Significant difference (P < 0.05) from the value after wheat crop within each site.* [10]

A rye cover crop and manure applications are complementary. Manure nutrients aid in decomposition of the rye, offsetting any potential yield drag, and rye captures and recycles the manure nutrients effectively to future crops, reducing commercial fertiliser needs.

9 V Gupta, S Kroker, D Smith, B Davoren, R Llewellyn,, A Whitbread (2011) Karoonda break crops trails—soil biology and rhizoctonia disease. Mallee Sustainable Farming, https://publications.csiro.au/rpr/pub?list=BRO&pid=csiro:EP111477

10 Gupta V, Kroker S, Smith D, Davoren B, Llewellyn R, Whitbread A. (2011). Karoonda break crops trails—soil biology and rhizoctonia disease Mallee Sustainable Farming, https://publications.csiro.au/rpr/pub?list=BRO&pid=csiro:EP111477

Rye improves water quality because the plant's extensive root system takes up excess soil N that would otherwise leach to contaminate groundwater or surface water bodies. This N is taken up by the plant, and then it slowly becomes available to subsequent crops as the residues gradually decompose.

Rye roots can also extract P and other nutrients from deep in the soil profile and bring them to the surface, where they become available to subsequent crops. Expect considerable fertility improvement in the topsoil when growing rye as a catch crop. [11]

IN FOCUS

Winter cover crop effects on soil organic carbon in soil.

Winter cover crops may increase SOC levels or reduce their rate of depletion. Selection of appropriate cover crops to increase SOC requires knowledge of the quality and quantity of plant biomass produced and its rate of decomposition in soil. This study in the north-west United States examined the SOC and carbohydrate concentrations in soil as affected by several leguminous and non-leguminous cover crops in a temperate, humid region. With more than 4 Mg/ha of shoot biomass, cereal rye and annual ryegrass were better suited as winter cover crops for building SOC levels in this region than Austrian winter pea, hairy vetch, and canola. [12]

5.1.2 Fertiliser application

Most varieties cereal rye do not require any additional fertiliser over that required by other cereals. However, given its ability to produce winter feed very quickly, strong economic responses can be gained from supplying the crop with a good amount of starter fertiliser (e.g. upwards of 100 kg/ha of di-ammonium phosphate). Follow up with a topdressing of N (30–50 kg/ha) when the crop is at early tillering stages, perhaps three weeks after emergence. Additional fertiliser can be applied according to a soil test result. [13]

Phosphorus is the nutrient most generally applied as fertiliser for rye; N is also used to some extent in higher rainfall areas. The rate of P application varies from about 6–18 kg/ha, lighter applications being used in drier districts. Rye does not utilise N as efficiently as oats. [14]

Phosphorus and, where necessary, N fertilisers are recommended at the same rates as for wheat. The current recommendations for the Mallee are:

- P at 10–15 kg/ha and N at 10–20 kg/ha applied at sowing.
- N broadcast post-sowing if the crop appears deficient. [15]

Application considerations

Use higher rates of N fertiliser where N is known to be deficient, when double cropping or with large amounts of undecomposed stubble.

11 H Valenzuela, J Smith J (2002) Rye. Sustainable agriculture green manure crops. University of Hawai'i, https://www.ctahr.hawaii.edu/oc/freepubs/pdf/GreenManureCrops/rye.pdf

12 S Kuo, UM Sainju, EJ Jellum (1997) Winter cover crop effects on soil organic carbon and carbohydrate in soil. *Soil Science Society of America Journal* 61, 145–152,

13 Wrightson seeds (2010) Southern Green forage rye. Forage Focus. Wrightson Seeds, http://www.pggwrightsonseeds.com.au/assets/FTP-Uploads/Forage_Focus/Cereals/FF_Southern-Green-Forage-Ryecorn.pdf

14 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

15 Agriculture Victoria (2013) Growing cereal rye. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Rates should be reduced by 50% for very sandy soil sand may be increased by 30% for heavy-textured soils or under good soil moisture conditions at planting.

Rates should be reduced by 50% when using planting equipment with narrow slit openers because the fertiliser concentration is increased around the seed.

Rates may be increased by 50% when air seeders are used operating at high pressures with seeding points giving wider (>5 cm) seed spread in the furrow. Air seeders spread the fertiliser bands when operating at high pressures reducing the fertiliser concentration around the seed. [16]

IN FOCUS

Agronomic requirements of a new semi-dwarf rye variety: N and P

Cereal rye is an important crop for the control of erosion on marginal soil types. This experiment was conducted near Lameroo, South Australia, to examine the responses of B88 and the current variety, SA Commercial to N fertiliser at two levels of P. Triticale (cv. Currency) and wheat (cv. Halberd), which usually yield poorly on these light soil types were also included to compare their responses to higher levels of N and P.

The trial was sown on 14 June 1988 on the side of an eroded sand bank, and received a basal application of 2 kg Cu, 5 kg Zn and 20 kg K/ha. The seed was coated with MnSO4. The June–November rainfall (210 mm) was 10% below average largely due to a dry spring. The experimental design was a split plot with varieties as main treatments and a factorial of six N by two P treatments as subplots. P (10, 40 kg P/ha) was applied with the seed as double superphosphate and N applications (0, 10, 20, 40, 80, 160 kg N/ha as ammonium nitrate) were split equally between sowing and 7 weeks post-sowing. Commercial sowing rates were used (40 kg/ha for the rye lines and 70 and 50 kg/ha for triticale and wheat respectively). Limited availability of seed of B88 restricted sowing to three replicates. Grain yield and yield components were measured at harvest.

Grain yield responded significantly to N but not to P. There were significant variety × N effects (Figure 3). B88 outyielded SA Commercial at all rates and had a higher optimum of 80 kg N/ha. The rye varieties had a lower optimum N rate than the wheat and triticale varieties, both of which responded to N applications up to the maximum rate.

The response to N was significant for all yield components but the only significant effect of P was to increase grain weight. The yield components also showed significant variety × fertiliser differences. B88 had a high number of ears/m^2 at zero N and responded to further N almost solely through an increase in the number of functional tillers, whereas the triticale produced a higher number of spikelets/ear and grains/spikelet with N applications. [17]

16 DinoFert. Cereal Rye, http://www.dinofert.com.au/technical-information/plant-nutrition-guide/item/142-cereal-rye

17 G Dean, G McDonald (1989) Agronomic requirements of a new semi-dwarf rye variety 2. nitrogen and phosphorus. 5th Australian Agronomy Conference, http://www.regional.org.au/au/asa/1989/contributed/plant-nutrition/p-04.htm

MORE INFORMATION

GRDC Fact Sheet: Targeted nutrition at sowing

VIDEOS

WATCH: Over the Fence: Precision agriculture pays at Mildura

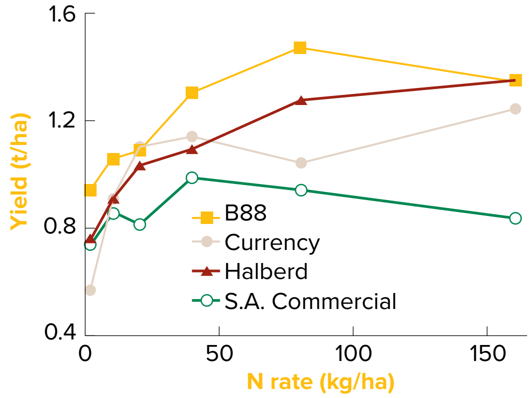


Figure 3: *Grain yield response of varieties to N.* [18]

Source: Dean and McDonald 1989

5.1.3 Fungi and soil health

Arbuscular mycorrhizal fungi (AMF) penetrate the roots of vascular plants, helping them to capture nutrients from the soil. These fungi are 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 symbiosis with AMF.

The microscopic fungal fibres extend vastly into the root system. They extract water and nutrients from a large volume of surrounding soil and bring them into the plant, improving nutrition and growth. The microscopic filaments grow through the soil and reach a much greater quantity of nutrients than the roots would be able to do on their own.

In cropping systems, most plants have mycorrhizal associations and depend, to varying degrees, on these fungi to supply them with nutrients such as P and zinc (Zn). In turn, the plant hosts the fungus and supplies it with carbohydrates.

Unlike saprobic soil fungi, which colonise and break down organic matter and do not require a host plant complete their lifecycle, AMF require the presence of a host to reproduce and are therefore obligate symbionts. They produce spores as a means of survival in soil during absence of a host (e.g. a clean fallow); these spores germinate and colonise host roots when available. Hyphae in soil or in roots in the soil may also grow to new roots; however, they survive for shorter periods in the soil than the spores.

The longer a fallow, the less chance of survival of AMF spores, and this causes the yield-reduction syndrome known as long-fallow disorder. AMF levels can also be severely reduced by periods of drought, or the growth of non-host crops.

Primarily, long-fallow disorder is a deficiency of P or Zn of the plant and can be overcome by the application of P and/or Zn fertilisers. Having adequate populations of AMF present in soils is therefore beneficial and in some cases essential for crop growth. Without AMF, much higher rates of P and/or Zn fertiliser are required to attain the same level of productivity as when plants are mycorrhizal.

18 G Dean, G McDonald (1989) Agronomic requirements of a new semi-dwarf rye variety 2. nitrogen and phosphorus. 5th Australian Agronomy Conference, http://www.regional.org.au/au/asa/1989/contributed/plant-nutrition/p-04.htm

When reintroduced to the soil, the AMF colonise 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 root absorption.

Maintaining high mycorrhizal populations therefore 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 colonised by AMF as they require without AMF for the same level of production. [19]

In one study, the colonisation of rye roots with AMF was investigated at two sites, cultivated using conventional or biological-dynamic farming methods. AMF infection rate and infected root length were significantly higher at the site with biological-dynamic cultivation. The differences are thought to be due to several factors, such as the use of fertilisers and agro-chemicals, and the influence of crop rotation. [20]

Management to optimise AMF population

If you suspect low levels of AMF:

- Grow host crops with low or very low mycorrhizal dependency; e.g. wheat or barley will not suffer much yield loss but will increase the AMF 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.
- Adopt no-till or reduced tillage practices during fallow periods, because these practices are less harmful to AMF than frequent tillage. [21]

5.2 Crop removal rates

Ultimately, nutrients removed from paddocks will need to be replaced to sustain production (Table 1). In irrigated cropping, large quantities of nutrients are removed and growers need to adopt a strategy of programmed nutrient replacement. Dryland growers should also consider this approach. The yield potential of a crop will be limited by any nutrient the soil cannot adequately supply. Temperature and soil moisture content will affect the availability of nutrients to plants, as will soil pH, degree of exploration of root systems and various soil chemical reactions, which vary from soil to soil. Fertiliser may be applied in the top 5–10 cm, but unless the soil remains moist the plant will not be able to access it. Movement of nutrients within the soil profile in low-rainfall areas is generally low except in very sandy soils.

Lack of movement of nutrients combined with current farming methods (e.g. no-till) is resulting in stratification of nutrients, whereby nutrient concentrations build up in the surface of the soil, and depending on the seasonal conditions, they are not always available to plants. [22]

Table 1: *Estimated nutrient removal rates (kg/ha) of cereal rye grain and straw.*

Rye yield component	Yield per ha	Nitrogen	P_2O_5	K_2O	Calcium	Magnesium	Sulfur	Copper	Manganese	Zinc
Grain	1.88 t	39	11	11	2.2	3.4	7.9	0.022	0.25	0.034
Straw	3.36 t	17	9	28	9	2.2	3.4	0.011	0.16	0.079

Source: converted from North Caroline State University

19 N Seymour N (2009) Mycorrhizae and their influence on P nutrition. GRDC Update Papers, September 2009, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2009/09/Mycorrhizae-and-their-influence-on-P-nutrition

20 B Sattelmacher, S Reinhard, A Pomikalko (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, 350–355.

21 N Seymour N (2009) Mycorrhizae and their influence on P nutrition. GRDC Update Papers, September 2009, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2009/09/Mycorrhizae-and-their-influence-on-P-nutrition

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

5.3 Soil testing

Key points:

- A soil test critical value is the soil test required to achieve 90% of maximum potential crop yield.
- A critical range is a range of soil test values used to determine whether a nutrient is deficient or adequate. The critical range reflects the degree of uncertainty around the critical value.
- Results from more than 2,200 trials from south-eastern Australia have been compiled into a database and used to estimate soil test critical values and ranges.
- Revised soil test critical values and ranges have been established for nutrients, crops and soil classes.
- A soil test indicates whether there is sufficient nutrient supply to meet the crop's demand:
  - » A value above the critical range indicates that a crop yield response to added nutrients is unlikely.
  - » A value below the critical range indicates that a crop yield response to added nutrients is likely.
- Critical ranges for particular crops and soils have been established for 0–10 cm.
- Soil sampling to greater depth (to 60 cm) is considered important for the more mobile nutrients such as N, K and sulfur (S) as well as for pH, salinity and sodicity.
- Use local data and support services to help integrate soil test data into making profitable fertiliser decisions.

In south-eastern Australia profitable grain production depends on applied fertilisers, particularly N, P and to a lesser extent, K, S, Zn, manganese (Mn) and copper (Cu).

Fertiliser is a major cost for grain growers, so careful selections of crop nutrients is a major determinant of profit. Both under- and over-fertilisation can lead to economic losses, the former through unrealised crop potential and the latter from wasted inputs.

Before deciding on how much fertiliser to apply, it is important to know the quantities of available nutrients in the soil, where they are located in the soil profile and the likely demand for nutrients in that season.

The values from appropriate soil tests can be compared against critical nutrient values and ranges to indicate which nutrients are limiting or adequate.

Soil test critical values inform growers about whether a crop is likely to respond to added fertiliser, but without further information, they do not predict optimum fertiliser rates.

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

5.3.1 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, salinity, or high concentrations of aluminium or boron), and to quantify the a soilborne 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, sodicity (sodium) and salinity (soluble salts), which affect the crop demand for and ability to access nutrients
- zoning paddocks for variable application rates

- as a diagnostic tool to identify reasons for poor plant performance.

Soil test results are part of the information that supports decisions about fertiliser rate, timing and placement.

To determine micronutrient status, however, plant tissue testing is usually more reliable. [23]

MORE INFORMATION

QDAF: Soil nutrient testing: How to get meaningful results

GRDC Fact Sheet: Soil testing for crop nutrition – Southern Region

5.3.2 Basic requirements

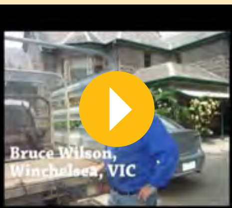
Three basic steps must be followed if meaningful results are to be obtained from soil testing:

1. Take a representative sample of soil for analysis.
2. Analyse the soil by using the accepted procedures that have been calibrated against fertiliser experiments in that particular region.
3. 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. [24]

VIDEOS

WATCH: Over the Fence: Raised beds boost crops in Victoria's high rainfall zone.



5.3.3 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
- 2 M KCl-extractable inorganic N, for measurement of nitrate-N and ammonium-N.

For determining crop N requirement, soil testing can be unreliable because soil N availability and crop demand for N are highly influenced by seasonal conditions. Ideally, soil testing for N should be carried out as close to sowing as possible, after allowing for results to be returned.

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-absorption capacity (measured as P-buffering index, PBI), electrical conductivity, chloride, and cation exchange capacity (CEC) including aluminium. [25]

5.4 Plant and/or tissue testing for nutrient levels

5.4.1 Why measure nutrients in plant tissues?

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

Of the many factors affecting crop quality and yield, soil fertility is one of the most important. 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 symptoms appear on the plant. The only way to know whether a crop is adequately nourished is to have plant tissue analysed during the growing season.

23 GRDC (2014) Crop nutrition: Soil testing for crop nutrition—Southern Region. GRDC Fact Sheet, January 2014, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

24 D Loch. Soil nutrient testing: how to get meaningful results. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/__data/assets/pdf_file/0006/65985/Soil-Nutrient-Testing.pdf

25 GRDC (2014) Crop nutrition: Soil testing for crop nutrition—Southern Region. GRDC Factsheet, January 2014, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

5.4.2 What plant-tissue analysis shows

Plant tissue analysis shows the nutrient status of plants at the time of sampling. This, in turn, shows whether soil nutrient supplies are adequate. In addition, plant tissue analysis will detect unseen deficiencies and may confirm visual symptoms of deficiencies. Toxic levels also may be detected.

Although usually used as a diagnostic tool for correction of future nutrient problems, plant tissue analysis from young plants will allow a corrective fertiliser application in the present season.

A plant analysis is of little value if the plants come from fields that are infested with weeds, insects and disease organisms, or if the plants are moisture-stressed or 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 of a crop periodically during the season or sampling once each year provides a record of 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 tailor fertiliser practices to specific soil–plant needs.

Sampling tips:

- Sample the correct plant part at the specified time or growth stage (Table 2).
- Use clean plastic disposable gloves to sample to avoid contamination.
- Sample tissue (e.g. entire leaves) from vigorously growing plants unless otherwise specified in the sampling strategy.
- Take a sufficiently large sample (adhere to guidelines for each species provided).
- When troubleshooting, take separate samples from areas of good and poor growth.
- Where necessary, wash samples while fresh to remove dust and foliar sprays.
- After collection, keep samples cool.
- Refrigerate or dry if samples cannot be dispatched to the laboratory immediately for arrival before the weekend.
- Generally sample in the morning while plants are actively transpiring.

Practices to avoid:

- sampling spoiled, damaged, dead or dying plant tissue
- sampling plants stressed by environmental conditions
- sampling plants affected by disease, insects or other organisms
- sampling soon after applying fertiliser to the soil or foliage
- contaminating samples with dust, fertilisers and chemical sprays or perspiration and sunscreen from hands
- sampling from atypical areas of the paddock, e.g. poorly drained areas
- sampling plants of different vigour, size and age
- combining samples from different cultivars (varieties) to make one sample
- placing samples into plastic bags, which will cause the sample to sweat and hasten its decomposition
- sampling in the heat of the day, i.e. when plants are moisture-stressed
- mixing leaves of different ages. [26]

26 SoilMate (2010) Guidelines for sampling plant tissue for annual cereal, oilseed and grain legume crops. Back Paddock Co., http://www.backpaddock.com.au/assets/Product-Information/Back-Paddock-Sampling-Plant-Tissue-Broadacre-V2.pdf?phpMyAdmin=c59206580c88b2776783fdb796fb36f3

Table 2: *Plant tissue requirements for nutrient testing in wheat and triticale.*

Growth stage (Zadoks) to sample	Plant part	No. of samples required
Seedling to early tillering (Z14–21)	Whole shoots cut off 1 cm aboveground	40
Early tillering to 1st node (Z23–31)	Whole shoots cut off 1 cm aboveground	25
Flag leaf ligule just visible to boot swollen (Z39–45)	Whole shoots cut off 1 cm aboveground	25
Early tillering to 1st node (Z21-31)	Youngest expanded blade plus next two lower blades	40

Source: Back Paddock

5.5 Nitrogen

Key points:

- Rye is one of the best crop scavengers of N and reduces leaching losses on both sandy soils and tile-drained land.
- Nitrate (NO_3^-) is the highly mobile form of inorganic N in both the soil and the plant.
- Sandy soils in high-rainfall areas are most susceptible to nitrate loss through leaching.
- Nitrogen is needed for crop growth in larger quantities than any other nutrient.
- Soil testing and N models will help to determine seasonal N requirements.

The two forms of soil mineral N absorbed by most plants are nitrate and ammonium (NH_4^+). In well-aerated soils during the growing season, nitrate becomes the main form of N available for crops because microbial activity quickly transforms NH_4^+ into NO_3^- (see Figure 4). It is crucial to keep nitrate at an adequate level (but not too high); concentrations too low can limit crop production and too high can lead to environmental pollution. Soil nitrate concentrations vary across space and time. Proper agricultural management needs to consider both site-specific variations and temporal patterns in soil nitrate to supply optimum amounts from both organic and mineral sources. [27]

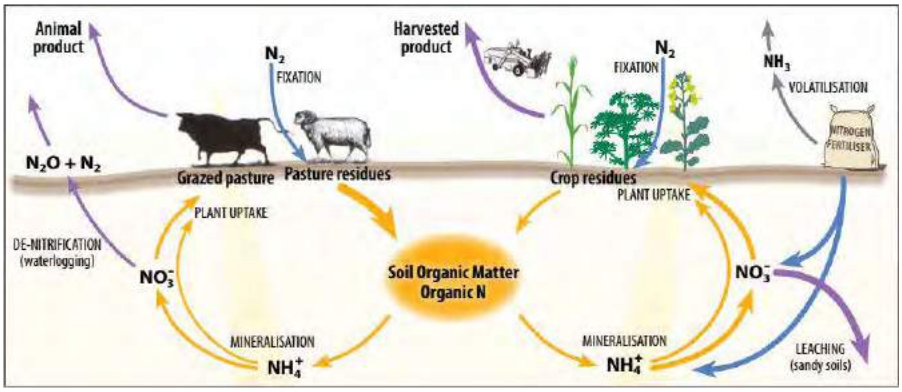


Figure 4: *Principle N cycling pathways in a mixed cropping–pasture system* [28]

Adapted from Peverill et al. (1995). Source: Soil Quality Pty Ltd

As an efficient scavenger of N, rye can be used to reduce leaching losses on sandy soils and on tile-drained land. However, the ability of rye to affect soil N levels can depend on topography. In one study, a rye cover crop resulted in a

27 M Ladoni, AN Kravchenko, GP Robertson, (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. *PloS ONE* 10, e0143358.

28 KI Peverill, LA Sparrow, D Reuter J (1995) *Soil Analysis an Interpretation Manual*, CSIRO Publishing.

significant 15% reduction in nitrate-N in topographical depressions but not in slope and summit positions; the reasons for this are not fully understood but the low biomass of rye on terrain slopes compared with more fertile depressions could be a contributing factor. [29]

IN FOCUS

Accumulation and loss of N during growth and maturation of cereal rye

The loss of total N from herbage of cereal rye after anthesis was studied by recovering herbage, roots and anthers of rye grown in soil (under dryland conditions), nutrient solution and sand culture. The amount of N in herbage of dryland rye decreased an average of 7.9 kg/ha during the two weeks following anthesis. Potential loss of N from herbage through shedding of anthers and pollen was estimated at 16 kg/ha. Rye grown in sand or solution culture continued to absorb and accumulate N after anthesis, which masked the N lost during anthesis. There was no evidence to suggest a transport of N from herbage to roots under dryland conditions, or sand or nutrient culture. [30]

Rye will often respond to a modest application of N fertiliser, but when rye follows crops that have been well fertilised with N, this is seldom necessary. [31]

The amount of N safely placed with the seed will vary depending on soil texture, the type of seeding points used, amount of seedbed utilisation and moisture conditions. Higher rates of N can be safely applied with the seed if it is a polymerised form of urea where the N 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 N and P can be banded prior to seeding, but take care to avoid loss of seedbed moisture and protective crop residue. [32]

IN FOCUS

Nitrate leaching under a cereal rye cover crop.

Winter cover crops have potential to capture excess nitrate and reduce leaching by recycling nutrients. This three-year study (1992–95) compared winter NO3-N leaching losses under winter fallow and a winter cover crop of cereal rye following the harvest of sweet corn or broccoli. Leachate was sampled with passive capillary wick samplers. Without disturbing the overlying soil profile, 32 samplers (0.26 m^2) were installed at a depth of 1.2 m in a Willamette loam in Oregon, USA. The randomised complete-block split-plot design of this cover crop–crop rotation study (initiated in 1989) has cropping system (winter fallow *v.* winter cereal rye) as main plots and three N application rates as subplots. At the recommended N rate for the summer crops, nitrate leaching losses were 48 kg N/ha under sweet corn–

29 M Ladoni, AN Kravchenko, GP Robertson, (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. PloS *ONE* 10, e0143358.

30 CB Rumburg, FA Sneva (1970) Accumulation and loss of N during growth and maturation of cereal rye (*Secale cereale*). *Agronomy Journal* 62, 311–313.

31 V Grubinger (2010) Winter rye: A reliable cover crop. University of Vermont Extension, https://www.uvm.edu/vtvegandberry/factsheets/winterrye.html

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

winter fallow for winter year1, 55 kg N/ha under broccoli–winter fallow for winter year 2 and 103 kg N/ha under sweet corn–winter fallow for winter year 3. These losses were reduced to 32, 21, and 69 kg N/ha, respectively, under winter cereal rye. For the first two winters, most of the variation (61%) in nitrate leaching was explained by N rate (29%), cereal rye N uptake (17%) and volume of leachate (15%). Seasonal, flow-weighted concentrations at the recommended N rate were 13.4 mg N/L under sweet corn–winter fallow (year 1), 21.9 mg N/L under broccoli–winter fallow and 17.8 mg N/L under sweet corn–winter-fallow (year 3), which were reduced by 39%, 58%, and 22%, respectively, under winter cereal rye. [33]

5.5.1 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 1).
- Double-sown areas have fewer symptoms if N 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 2).
- 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.
- N-deficient plants develop more slowly than healthy plants, but maturity is not greatly delayed.
- Reduced grain yield and protein levels.

33 FM Brandi-Dohrn, M Hess, JS Selker, RP Dick, SM Kauffman, DD Hemphill (1997) Nitrate leaching under a cereal rye cover crop. *Journal of Environmental Quality* 26, 181–188.

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

Source: [Department of Agriculture and Food Western Australia]()

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

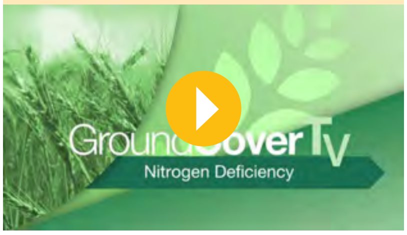
Source: [Department of Agriculture and Food Western Australia]()

Deficiency symptoms can be treated with N fertiliser or foliar spray. NOTE: There is a risk of volatilisation loss from urea (or ammonium sources of N on alkaline soils) when topdressed on dry soils in dewy conditions. Losses rarely exceed 3% per day. [34]

34 DAFWA. Diagnosing nitrogen deficiency in wheat, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogenN-deficiency-wheat

VIDEOS

WATCH: GCTV14: N deficiency.



What else could it be?

Condition	Similarities	Differences
Waterlogging	Pale plants with oldest leaves most affected	Root browning or lack of feeder roots and wet soil
Potassium deficiency	Pale plants with oldest Leaves most affected	Differences include more marked leaf tip death and contrast between Yellow and green sections of K-deficient plants. Tillering is less affected
Molybdenum deficiency	Pale poorly tillered plants	Molybdenum deficiency affects the middle leaves first and causes white heads, shrivelled grain and delayed maturity

5.5.2 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 chance of achieving a yield response similar to that achieved with an application at sowing is less.
- There is no consistent difference in the response to N between different forms of N fertiliser.
- In general, increases in grain protein concentration are greater with N applications between flag-leaf emergence and flowering.
- Volatilisation losses can be significant in some cases; the greatest risk is with urea and lower with UAN (urea ammonium nitrate) and ammonium sulfate. [35]

Nitrogen fertilisers are a significant expense for broadacre farmers, and optimising use of fertiliser inputs can reduce this cost. There are four main sources of N available to crops: stable organic N, rotational N, ammonium and nitrate. To optimise the ability of the plant to use soil N, growers need to be aware of how much of each source is present initially. The best method of measuring these N sources is soil testing.

Timing of application

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

Later N applications can also have yield benefits through increased tiller survival, leaf duration and photosynthetic area. Delaying application, however, reduces the chance that economic response to N will be achieved. An advantage of late applications (first node visible) is that growers have a better idea of yield potential before applying the N. [36]

Budgeting

The critical factor in budgeting is the target yield and protein percentage, because crop yield potential is the major driver of N requirement. As a guide, Table 3 shows the N required for different yield and protein combinations at maturity and anthesis. For example, a target crop of 3 t/ha at 11% protein requires ~62 kg N/ha to be taken up by flowering. The amount of fertiliser N required will depend on the estimate of fertiliser recovery; a 50% recovery, means a supply of 134 kg N/ha.

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

36 R Quinlan, A Wherrett (2013) Nitrogen—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/nitrogen-nsw

Predicting yield during the growing season is crucial to allow growers to make tactical decisions on N management. Experience in the mid-North of South Australia has shown that the decision-making tool Yield Prophet® can predict yields accurately in mid-August and can assist with N-application decisions. Other tools, such as the Yield and N Calculators, provide a way of calculating N budgets and estimating N requirements. [37]

Table 3: *Nitrogen requirements (kg N/ha) for cereal crops at different combinations of yield and grain protein at maturity and the corresponding N required at anthesis. 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

5.6 Phosphorus

Key points:

- Phosphorus is one of the most critical and limiting nutrients in agriculture in Australia.
- Cycling of P in soils is complex.
- Only 5–30% of P applied as fertiliser is taken up by the plant in the year of application.
- Fertiliser P is best applied at seeding.
- In rye, P is the nutrient most generally applied as fertiliser. The rate of P application varies from about 6 to 18 kg/ha, lighter applications being used in drier districts. [38]

Phosphorus is essential for plant growth, but few Australian soils have sufficient P for sustained crop and pasture production. Complex soil processes influence the availability of P applied, with many soils able to adsorb or 'fix' P, making it less available to plants (Figure 5). A soil's ability to fix P must be measured when determining P requirements for crops and pastures. [39]

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

38 RL Reid (Ed.) (2013) The manual of Australian agriculture. Elsevier.

39 Soilquality.org (2013) Phosphorus NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/phosphorus-nsw

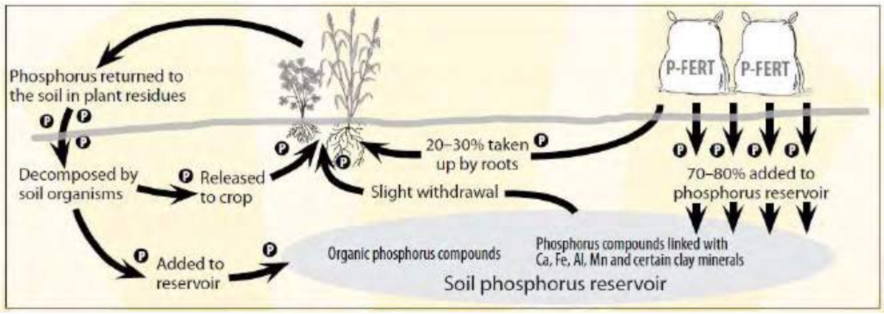


Figure 5: *The phosphorus cycle in a typical cropping system is very complex, where movement through the soil is minimal and availability to crops is severely limited (from the Fertiliser Industry Federation of Australia Inc. 2000 40).*

Source: Soil Quality Pty Ltd

In many soils of south-eastern Australia, P application has good residual value. However, if P is not applied for 5–10 years, even those soils with excellent fertiliser history are likely to develop a P deficiency.

Phosphorus has a tendency to leach out of sandy soils. Up to 100% of applied P can be lost to leaching in the first season, and losses of 50% are common. Soils with sufficient levels of 'reactive' iron (Fe) and aluminium (Al) will tend to resist P leaching. If a farm has sandy soils with low levels reactive of Fe and Al, then soil P levels should be tested and smaller amounts of P should be applied more often, so that P is not lost to leaching. In soils with high free lime (10–20%), P will react with calcium carbonate in the soil to create insoluble calcium phosphates. Lock-up of P occurs on these soils at high pH, and more sophisticated methods of application may be needed.

IN FOCUS

Uptake and utilisation of P from iron phosphate—rye shows efficiency

Two glasshouse experiments were conducted to evaluate genotypic variation amongst cereal genotypes for P uptake from relatively insoluble iron phosphate (FePO4). Two rates of FePO4 were selected representing a deficient and sufficient supply (26 and 339 mg P/kg soil, respectively). These rates were used to screen 99 wheat, eight triticale, and four cereal rye genotypes for P-use efficiency. Efficiency was rated by four criteria: shoot dry weight at deficient P supply, shoot weight at deficient supply relative to shoot weight at sufficient P supply, P-uptake efficiency (amount of P taken up per unit P supplied), and P-utilisation efficiency (shoot weight per unit P in plant). No genotype was rated as efficient under all criteria. Only two genotypes, both rye, were rated efficient (Bevy, PC00361) and one genotype inefficient (wheat cv. Machete) under three criteria. Significant genotypic variation was identified in cereals for the ability to take up and utilise P from poorly soluble FePO4, although all genotypes were able to utilise this source of P to some degree. [41]

40 Fertiliser Industry Federation of Australia Inc. (2000) Australian soil fertility manual. (Ed. JS Glendinning) CSIRO Publishing.

41 LD Osborne, Z Rengel (2002) Genotypic differences in wheat for uptake and utilisation of P from iron phosphate. *Australian Journal of Agricultural Research* 53, 837–844.

5.6.1 Managing phosphorus

Key points:

- After decades of consistent 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; pH($CaCl_2$) less than 4.5, water-repellent soil or high levels of root disease will reduce the availability of soil-test P. A yield increase to fertiliser P can occur even when the soil-test P results are adequate.
- Work with an adviser to refine your fertiliser strategy.
- Reserves of P will be run down over several decades of cropping.
- Adding fertiliser to the topsoil in systems that rely on stored moisture does not always place nutrients where crop needs them.
- Testing subsoil (10–30 cm) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Applying P at depth (15–20 cm on 50-cm bands) can improve yields over several cropping seasons (if other nutrients are not limiting).
- Addressing low P levels will usually increase potential crop yields, so the application of other essential nutrients, particularly N, should be matched to this adjusted yield potential. [42]

Place P with or near the seed at seeding time or band prior to seeding. High application rates can lead to salt burning of the seedlings and a thin plant stand, reducing potential yield. [43]

Rye has been found to be more efficient in taking up and utilising P than wheat at low rates of P supply. [44]

Plants have a high requirement for P during early growth. Because P is relatively immobile in the soil, topdressed or sprayed fertiliser cannot supply enough to correct a deficiency.

Phosphorus does leach on sands of very low PBI (a measure of P retention), particularly on coastal plains. Topdressing is effective on these soils. [45]

5.6.2 Phosphorus-deficiency symptoms

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.
- Plants look unusually water-stressed despite adequate environmental conditions (Photo 3).
- Affected areas are more susceptible to leaf diseases.

Plant:

- In early development, usually in cases of induced P deficiency, seedlings appear pale olive green and wilted (Photos 4 and 5).

42 GRDC (2012) Crop nutrition: Phosphorus management—Southern region. GRDC Fact Sheet, November 2012, www.grdc.com.au/GRDC-FS-PhosphorusManagement

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

44 LD Osborne, Z Rengel (2002) Screening cereals for genotypic variation in efficiency of phosphorus uptake and utilisation. *Australian Journal of Agricultural Research* 53, 295-303.

45 DAFWA. Diagnosing phosphorus deficiency in wheat, https://www.agric.wa.gov.au/mycrop/diagnosing-P-deficiency-wheat

- On older leaves, chlorosis starts at the tip and moves down the leaf on a front; the base of the leaf and the rest of the plant remains dark green. Unlike N deficiency, necrosis (death) of these chlorotic (pale) areas is quite 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 P deficiency.
- By tillering, (uncommon) symptoms of severe deficiency are dull, dark green leaves with slight mottling of the oldest leaf.

Photo 3: *Stunted early growth with reduced tillers in phosphorus-deficient crop on the left.*

Source: Department of Agriculture and Food Western Australia

Photo 4: *Phosphorus-deficient plants on the left are later maturing with fewer smaller heads.*

Source: Department of Agriculture and Food Western Australia

MORE INFORMATION

NRSE: Phosphorus in the South East Soils

GRDC Fact Sheet: Crop nutrition: Phosphorus management – Southern region

VIDEOS

WATCH: GCTV13: Phosphorus deficiency.

WATCH: Improving phosphate use efficiency

Photo 5: *Phosphorus deficiency. Dark leaves with necrosis moving down from the tip of the oldest leaf.*

Source: Department of Agriculture and Food Western Australia

What else could it be?

Nitrogen deficiency, molybdenum deficiency or potassium deficiency

Similarities: Small, less tillered and light green plants.

Differences: Phosphorus-deficient plants are thinner with darker leaves and tip death of older leaves without leaf yellowing.

5.6.3 Soil testing

Testing of soil P levels will help with budgeting of your P dollar.

The release of P is related to:

- the total amount of P in the soil
- the abundance of Fe and Al oxides
- organic carbon content
- Free lime/soluble calcium carbonate
- PBI

Available P tests such as the Colwell-P and Olsen-P tests do not measure available P. Rather, they express an indication of the rate at which P may be extracted from the soils. This indicator of rate is calibrated with field trials. There is a relationship between total soil P and Colwell-P and this can enable prediction of when a given level of P input (fertiliser) or output (product removal) will result in a risk of P rate of supply becoming a limiting factor. [46]

46 G Bailey, T Brooksby. Phosphorus in the South East Soils. Natural Resources South East, Government of South Australia, Eahttp://www.naturalresources.sa.gov.au/files/sharedassets/south_east/get_involved/land/140916-phosphorus-in-the-se.pdf

5.7 Sulfur

Historically, S has been adequate for crop growth because it is supplied in superphosphate, in rainfall in coastal areas and in some part from gypsum. In the southern region, S-responsive soils are uncommon in cereals but can be seen in canola. Inputs of S to cropping systems have declined with the use of low-S fertilisers such as triple superphosphate and mono- and di-ammonium phosphate. Sulfur is also subject to leaching and in wet seasons may move beyond the root-zone.

Occurrence of S deficiency appears to be a complex interaction between the mineralisation of S from soil organic matter, seasonal conditions, crop species and plant availability of subsoil S. Similar to N, these factors affect the ability of the soil S test to predict plant available S. [47]

Topdressing S at 10–15 kg per hectare as gypsum or ammonium sulfate will overcome deficiency symptoms.

Foliar sprays generally cannot supply enough S for plant needs. [48]

5.7.1 Sulfur deficiency symptoms

What to look for

Paddock:

- Areas of pale plants (Photo 6).

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 7).
- With extended deficiency the entire plant becomes lemon yellow and stems may become red.

47 GRDC (2014) Crop nutrition: Soil testing for crop nutrition—Southern Region. GRDC Factsheet, January 2014. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

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

Photo 6: *Areas of pale plants characterise sulfur deficiency. Note, however, that many other nutrient deficiencies also exhibit pale patches.*

Source: Department of Agriculture and Food Western Australia

Photo 7: *Sulfur deficiency: leaves remain healthy despite the yellowing.*

Source: Department of Agriculture and Food Western Australia

What else could it be?

Condition	Similarities	Differences
Iron deficiency in cereals	Pale new growth	Iron-deficient plants have interveinal chlorosis
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
Nitrogen, molybdenum and manganese deficiency; waterlogging	Pale growth	Youngest leaves of S-deficient plants are affected first while the middle or older leaves are affected first with the other conditions

5.8 Potassium

Key points:

- Rye can recycle K from deeper in the soil profile for future crop use. [49]
- Soil testing combined with plant tissue testing is the most effective means of determining K requirements.
- Banding away from the seed, at or within 4 weeks of sowing, is the most effective way to apply K when the requirement is less than 15 kg/ha.

49 Manure $ense (2009) Cereal rye: Manure and livestock's new best friend Midwest Cover Crops Council, http://mccc.msu.edu/wp-content/uploads/2016/09/MI_2009_CerealRyeManure.pdf

Potassium is an essential plant nutrient. It 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 K increases vigour and disease resistance of plants, and helps to form and move starches, sugars and oils. Available K exists as an exchangeable cation associated with clay particles and humus. [50]

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. 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. [51]

Topdressing K will generally correct deficiency. Foliar sprays generally cannot supply enough K to overcome a severe deficiency and can scorch crops. [52]

5.8.1 Potassium deficiency symptoms

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 8).
- Plants look unusually water-stressed despite adequate environmental conditions.
- Affected areas are more susceptible to leaf disease.

Plant:

- Plants appear paler and weak (Photo 9).
- 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.

50 Soilquality.org (2013) Potassium—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/potassium-nsw

51 GRDC (2014) Crop nutrition: Soil testing for crop nutrition—Southern Region. GRDC Factsheet, January 2014, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/01/soil-testing-for-crop-nutrition-south

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

Photo 8: *Header rows have less severe symptoms of potassium deficiency.*

Source: Department of Agriculture and Food Western Australia

Photo 9: *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: Department of Agriculture and Food Western Australia

What else could it be?

Condition	Similarities	Differences
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
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
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 K deficiency is more marked in high growth plants in good seasons
Root-lesion nematode in cereals	Smaller, water-stressed pale plants	Root-lesion nematode affected plants have 'spaghetti' roots with few feeder roots

MORE INFORMATION

SARDI: Potassium responses observed in South Australian cereals

5.8.2 Assessing potassium requirements

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

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

Available of in the soil is measured by the Colwell-K or exchangeable K soil tests. The amount of K needed for plant nutrition depends on soil texture (Table 4).

Table 4: *Critical (Colwell) soil test thresholds for potassium (µg/g).* [5354]

	Deficient	Moderate	Sufficient
Cereal, canola, lupins, etc. [53]	<50	50–70	>70
Pasture legumes [54]	<100 (sand) <150 (clay loam)	100–140 (sand) 150–180 (clay loam)	>140 (sand) >180 (clay loam)

Source: Soilquality.org

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

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

5.8.3 Fertiliser types

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

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

5.8.4 Fertiliser placement and timing

Potassium generally stays very close to where it is placed in the soil. Banded K has been shown to be twice as accessible to the crop as topdressed K, likely related to improved availability for the emerging crop and decreased availability for weeds. Seed must be sown within 50 mm of the K drill-row; otherwise, seedlings may miss the higher levels of K. High band rates of K (>15 kg/ha) can inhibit sensitive crops (e.g. lupins, canola). If a paddock is severely deficient then K needs to be applied early in the season, at seeding or up to 4 weeks after. [55]

53 RF Brennan, MJ Bell (2013) Soil potassium—crop response calibration relationships and criteria for field crops grown in Australia, Crop & Pasture Science 64, 514–522, http://www.publish.csiro.au/cp/CP13006

54 CJP Gourley, AR Melland, RA Waller, IM Awty, AP Smith, KI Peverill, MC Hannah (2007) Making better fertiliser decisions for grazed pastures in Australia. Department of Primary Industries Victoria, June 2007, http://www.asris.csiro.au/downloads/BFD/Making%20Better%20Fertiliser%20Decisions%20for%20Grazed%20Pastures%20in%20Australia.pdf

55 Soilquality.org (2013) Potassium—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/potassium-nsw

5.9 Micronutrients

Important micronutrients for rye are boron, copper (Cu), Fe, manganese (Mn), zinc (Zn) and molybdenum. Rye response to micronutrients is generally low, except for Zn.

5.9.1 Zinc

Zinc deficiency is a nutritional constraint for crop production in Australia and is particularly widespread in cereals growing on calcareous soil. Rye has a higher Zn-use efficiency than other cereals. Rye possesses an exceptionally high ability to grow and yield well on severely Zn-deficient calcareous soils and it is therefore regarded as Zn-efficient. [56]

Zinc is an essential component of various enzyme systems for energy production, protein synthesis and growth regulation. Zn-deficient plants exhibit delayed maturity. The most visible Zn-deficiency symptoms are short internodes and a decrease in leaf size. Shortages of Zn are mostly found in sandy soils, low in organic matter. Deficiency occurs more often during cold, wet conditions and is related to reduced root growth and activity. Zn uptake by plants decreases with increasing soil pH and is adversely affected by high levels of available P and Fe in soil. [57]

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.
- Zn-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 these 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 10).
- Maturity is delayed. [58]

56 I Cakmak, H Ekiz, A Yilmaz, B Torun, N Köleli, I Gültekin, S Eker (1997) Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. *Plant and Soil* 188, 1–10.

57 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

58 DAFWA. Diagnosing zinc deficiency in wheat. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

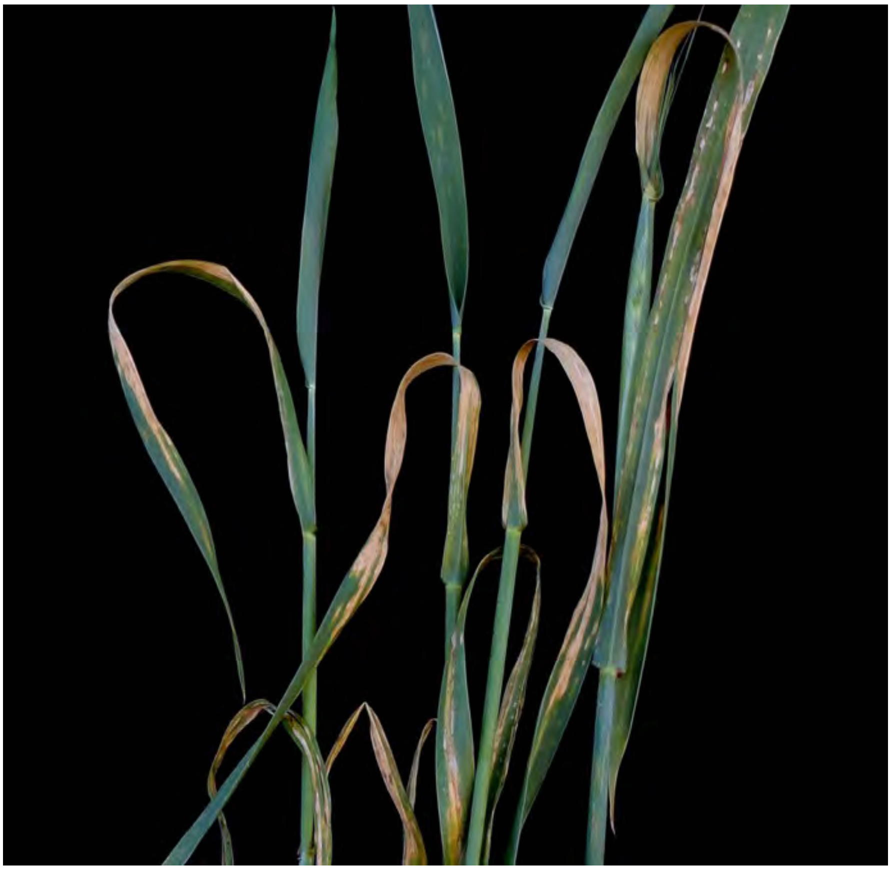


Photo 10: Zinc deficiency symptoms. Leaves yellow and die and can have tramline effect on leaves. Necrosis halfway along middle and older leaves causes them to droop.

Source: Department of Agriculture and Food Western Australia

What else could it be?

Condition	Similarities	Differences
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
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
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

IN FOCUS

Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils.

Field and greenhouse experiments were carried out to study the response of rye, triticale, two bread wheats, and two durum wheats to Zn deficiency and Zn fertilisation in severely Zn-deficient calcareous soils (DTPA-Zn, 0.09 mg/kg soil). The first visible symptom of Zn deficiency was a reduction in shoot elongation followed by the appearance of whitish brown necrotic patches on the leaf blades. These symptoms were either absent or only slight in rye and triticale, but occurred more rapidly and severely in wheats, particularly in durum wheats. The same was true for decrease in shoot dry matter production and grain yield. For example, in field experiments at the milk stage, decreases in shoot dry matter production from Zn deficiency were absent in rye, and were on average 5% in triticale, 34% in bread wheats and 70% in durum wheats. Zn fertilisation had no effect on grain yield in rye but enhanced grain yield of the other cereals. Zn efficiency of cereals, expressed as the ratio of yield (shoot dry matter or grain) produced under Zn deficiency relative to that under Zn fertilisation was, on average, 99% for rye, 74% for triticale, 59% for bread wheats and 25% for durum wheats.

These distinct differences among and within the cereal species in susceptibility to Zn deficiency were closely related to the total content of Zn per shoot, but not to Zn concentrations in shoot dry matter. For example, the most Zn-efficient rye and the Zn-inefficient durum wheat cultivar C-1252 did not differ in shoot Zn concentration under Zn deficiency, but the total amount of Zn per whole shoot was approximately 6-fold higher in rye than the durum wheat. When Zn was applied, rye and triticale accumulated markedly more Zn both per whole shoot and per unit shoot dry matter compared with wheats.

The results demonstrate an exceptionally high Zn efficiency of rye and show that, among the cereals studied, Zn efficiency declines in the order rye > triticale > bread wheat > durum wheat (Figure 6). The differences in expression of Zn efficiency are possibly related to a greater capacity of efficient genotypes to acquire Zn from the soil. [59]

59 I Cakmak, H Ekiz, A Yilmaz, B Torun, N Köleli, I Gültekin, S Eker (1997) Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. *Plant and Soil* 188, 1–10.

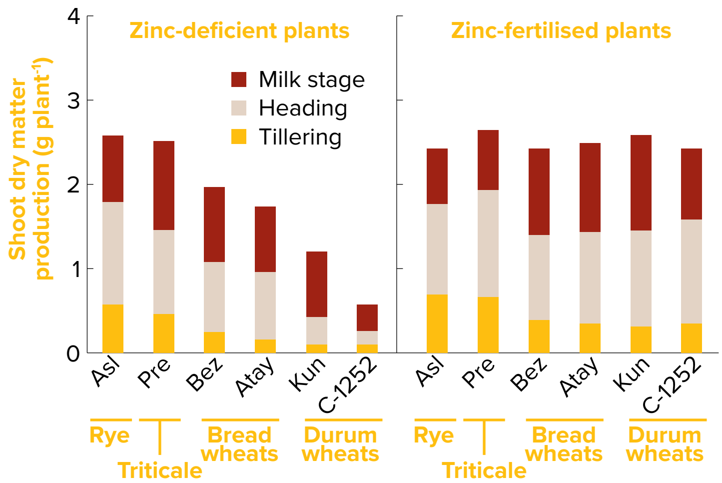


Figure 6: *Dry matter production of different cereals grown in a field experiment without and with Zn fertiliser (23 kg Zn/ha) in a Zn-deficient calcareous soil. Plants (main tillers) were sampled at the stages of tillering, heading and milk stages, respectively, 105, 144 and 168 days after 1 January.* [60]

Managing zinc deficiency

- Foliar spray (effective only in current season) or drilled soil fertiliser.
- Foliar sprays of Zn need to be applied as soon as deficiency is detected to avoid irreversible damage.
- Because Zn is immobile in the soil, topdressing is ineffective, only being available to the plant when the topsoil is wet.
- Mixing Zn throughout the topsoil improves availability through more uniform nutrient distribution.
- Deep-drilling of Zn increases the chances of roots being able to obtain enough Zn when the topsoil is dry.
- Seed treatment with Zn 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.
- The Zn present in compound fertilisers often meets the current requirements of the crop. [61]

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 Zn for plant uptake. Most of the alkaline soils in Victoria occur in the Wimmera and Mallee, but there are a few pockets of alkaline soils in the higher rainfall areas of the state. Zn responses on pasture are rare, but where required it should be applied at about 1–2 kg/ha, every 5–6 years. [62]

60 I Cakmak, H Ekiz, A Yilmaz, B Torun, N Köleli, I Gültekin, S Eker (1997) Differential response of rye, triticale, bread and durum wheats to zinc deficiency in calcareous soils. *Plant and Soil* 188, 1–10.

61 DAFWA. Diagnosing zinc deficiency in wheat. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-zinc-deficiency-wheat

62 Agriculture Victoria (2008) Trace elements for dryland pastures. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/trace-elements-for-dryland-pastures

IN FOCUS

Role of rye chromosomes in improvement of zinc efficiency in wheat and triticale

Wheat–rye addition lines and a triticale line as well as the respective wheat and rye parents were used in greenhouse experiments to study the role of rye chromosomes on the severity of Zn-deficiency symptoms, shoot dry matter production, Zn efficiency, shoot Zn concentration and Zn content. Plants were grown in a Zn-deficient calcareous soil with and without Zn supply (10 mg Zn/kg soil). Zn efficiency was calculated as the ratio of dry weight produced under Zn deficiency to that under Zn fertilisation. In the experiments with addition lines, visual Zn deficiency symptoms were slight in the rye cultivar (King-II), but severe in the wheat cultivar (Holdfast). The addition of rye chromosomes, particularly 1R, 2R and 7R, into Holdfast reduced the severity of deficiency symptoms. Holdfast showed greater decreases in shoot dry matter production from Zn deficiency and thus had a low Zn efficiency (53%), whereas King-II had a higher Zn efficiency (89%). With the exception of the 3R line, all addition lines had higher Zn efficiency than their wheat parent: the 1R line had the highest Zn efficiency (80%). In the experiment with the triticale cultivar and its parents, rye cv. Pluto and wheat cv. Fakon, Zn-deficiency symptoms were absent in Pluto, slight in triticale and very severe in Fakon. Zn efficiency was 88% for Pluto, 73% for triticale and 64% for Fakon. Such differences in Zn efficiency were better related to the total amount of Zn per shoot than to the amount of Zn per unit dry weight of shoot. Only in the rye cultivars was Zn efficiency closely related to Zn concentration. Triticale was more similar to rye than to wheat regarding Zn concentration and Zn accumulation per shoot under both Zn-deficient and Zn-sufficient conditions.

The results show that rye has an exceptionally high Zn efficiency, and rye chromosomes, particularly 1R and 7R, carry genes controlling Zn efficiency. [63]

5.9.2 Manganese

Rye was found to be tolerant of Mn deficiency in soils in South Australia, where is has not responded to Mn fertiliser.

63 I Cakmak, R Derici, B Torun, I Tolay, HJ Braun, R Schlegel (1997) Role of rye chromosomes in improvement of zinc efficiency in wheat and triticale. *Developments in Plant and Soil Sciences* 78, 237–241, http://link.springer.com/chapter/10.1007%2F978-94-009-0047-9_65

IN FOCUS

Tolerance of barley and other cereals to manganese-deficient calcareous soils of South Australia

Manganese deficiency is still a widespread problem in southern Australia, although the magnitude of crop loss often depends on seasonal conditions. On the calcareous sands, however, Mn deficiency is both chronic and severe, yields without Mn fertiliser ranging from 40% to 75% of those with Mn. Further, since the pH of these soils is high (pH 8–9) soil-applied Mn fertiliser quickly reverts in the soil to unavailable forms, and one or two foliar sprays of Mn during growth are commonly required for satisfactory cereal production. Rye was found to be tolerant of Mn deficiency in soils, where it is has not responded to Mn fertiliser. [64]

Deficiency symptoms

Paddock

- Mn deficiency often appears as patches of pale, floppy plants in an otherwise green healthy crop (Photo 11).

Plant

- Frequently, plants are stunted and they occur in distinct patches.
- Initially middle leaves are affected, but it can be difficult to determine which leaves are most affected as symptoms rapidly spread to other leaves and the growing point (Photo 12).
- Leaves develop interveinal chlorosis and/or white necrotic flecks and blotches.
- Leaves often kink, collapse and eventually die.
- Tillering is reduced, with extensive leaf and tiller death. With extended deficiency, the plant may die.
- Surviving plants produce fewer and smaller heads.

64 RD Graham, WJ Davies, DHB Sparrow, JS Ascher (1983) Tolerance of barley and other cereals to manganese-deficient calcareous soils of South Australia. In Genetic aspects of plant nutrition. pp. 339–345. Springer.

Photo 11: *Manganese efficiency: patches of pale floppy plants in otherwise healthy crop.*

Source: Department of Agriculture and Food Western Australia

Photo 12: *Middle leaves are affected first by manganese deficiency, showing yellowing and necrosis.*

Source: Department of Agriculture and Food Western Australia

What else could it be?

Condition	Similarities	Differences
Zinc deficiency in wheat	Pale plants with interveinal chlorosis and kinked leaves	Differences include linear 'tramline' necrosis on Zn-deficient plants. Mn-deficient plants are more yellow and wilted
Nitrogen deficiency in wheat	Pale plants	Nitrogen-deficient plants do not show wilting, interveinal chlorosis, leaf kinking and death
Waterlogging in cereals	Pale plants	Waterlogged plants do not show wilting, interveinal chlorosis, leaf kinking and death
Iron deficiency in cereals	Pale plants	New leaves are affected first and plants do not die
Sulfur deficiency in cereals	Pale plants	New leaves are affected first and plants do not die

Managing manganese deficiency

- Use foliar spray.
- Acidifying ammonium-N fertilisers can reduce Mn deficiency by lowering pH and making Mn more available to growing crops.
- Mn fertiliser is effective but expensive as high rates and several applications are required to generate residual value.

- Seed Mn-coating treatments have little effect in correcting the deficiency. [65]

5.9.3 Copper

Copper is necessary for carbohydrate and N metabolism, with inadequate Cu resulting in stunting. Cu is also required for lignin synthesis, which is needed for cell wall strength and prevention of wilting. Deficiency symptoms of Cu are dieback of stems, yellowing of leaves, stunted growth and pale green leaves that wither easily. Cu deficiencies are mainly reported in sandy soils, which are low in organic matter. Cu uptake decreases as soil pH increases. Increased P and Fe availability in soils decreases copper uptake by plants. Rye is efficient at taking up available Cu from the soil. [66]

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 13).
- After head emergence, mildly affected areas have disorganised wavy heads. Severe patches have white heads and discoloured late-maturing plants.
- Symptoms are often worse on sandy or gravelly soils where root-pruning herbicides have been applied and recently limed paddocks.

Plant

- Youngest growth is affected first.
- First sign of Cu deficiency before flowering is growing point death and tip withering, and/or bleaching and twisting up to half the length of young leaves (Photo 14).
- 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.

65 DAFWA. Diagnosing manganese deficiency in wheat. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-wheat

66 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

Photo 13: *Copper deficiency symptoms: pale necrotic flag leaf at head emergence.*

Source: Department of Agriculture and Food Western Australia

Photo 14: *Copper deficiency symptoms: partly sterile head and twisted flag leaf.*

Source: Department of Agriculture and Food Western Australia

What else could it be?

Condition	Similarities	Differences
False black chaff in wheat	Discoloration on the upper stem and glumes	False black chaff does not affect yield or grain quality
Molybdenum deficiency in cereals	White heads and shrivelled grain.	Molybdenum deficiency affects middle leaves first rather than the youngest leaf
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
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)
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.
- Cu foliar sprays are not effective after flowering because sufficient Cu is required pre-flowering for pollen development.
- Mixing Cu throughout the topsoil improves availability though more uniform nutrient distribution.
- Cu is immobile in the soil, so topdressing is ineffective; it is only being available to the plant when the topsoil is wet.
- In long-term no-till paddocks, frequent small applications of Cu via drilled or in-furrow application reduces the risk of plant roots not being able to obtain the nutrient in dry seasons.
- Deep-drilled Cu increases the chances of roots being able to obtain enough Cu when the topsoil is dry.
- Seed treatment with Cu is insufficient to for plant requirement in the current season. [67]

Although plants do have a requirement for Cu, the main reason it is applied is for the benefit of grazing stock. Cu deficiency is more common on light-textured soils such as sands or sandy loams. Where required, Cu is normally applied with the fertiliser at 1–2 kg/ha every 3–6 years. Inclusion of Cu in the fertiliser will provide a long-term supply to pasture and grazing stock. Cu is commonly applied in southern Victoria and on lighter soil types in western Victoria and parts of Gippsland whenever molybdenum is applied. Cu is not normally applied in northern Victoria. [68]

5.9.4 Iron

Iron is involved in the production of chlorophyll and is a component of many enzymes associated with energy transfer, N reduction and fixation and lignin formation. Fe deficiencies are mainly manifested as yellow leaves due to low levels of chlorophyll. Leaf yellowing first appears on the younger upper leaves in interveinal tissues. Severe Fe deficiencies cause the leaves to turn completely yellow or almost white, and then brown as leaves die. Fe deficiencies are found mainly in alkaline soils, although some acidic, sandy soils, low in organic matter, may also be Fe-deficient. Cool, wet weather enhances Fe deficiencies especially in soils with marginal levels of

67 DAFWA. Diagnosing copper deficiency in wheat. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-wheat

68 Agriculture Victoria (2008) Trace elements for dryland pastures. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/trace-elements-for-dryland-pastures

available Fe. Poorly aerated or compacted soils also reduce Fe uptake. High levels of available P, Mn and Zn in soils can also reduce Fe uptake. [69]

Symptoms

Paddock

- Pale plants, particularly in waterlogged or limed areas (Photo 15).

Plant

- Youngest growth is affected first and most severely.
- Symptoms begin with young leaves turning pale green or yellow.
- Interveinal areas become yellow and, in severely deficient plants, turn almost white (Photo 16).
- 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 15: *Iron deficiency symptoms: pale green to yellow plants.*

Source: Department of Agriculture and Food Western Australia. Photo: courtesy CSIRO Publishing

69 RH Schlegel (2013) Rye: genetics, breeding, and cultivation. CRC Press.

Photo 16: *Pale yellow, iron-deficient leaves, most showing prominent green veins (right) compared with dark green healthy leaf (left).*

Source: Department of Agriculture and Food Western Australia

What else could it be?

Condition	Similarities	Differences
Sulfur deficiency in cereals	Pale plants with pale new growth	Sulfur-deficient plants do not have interveinal chlorosis
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
Nitrogen, molybdenum and manganese deficiency; waterlogging	Pale growth	Middle or older leaves are affected first

Managing iron deficiency

- No yield responses to Fe 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. [70]

5.10 Aluminium toxicity

The ability of crops to overcome aluminium (Al) toxicity varies among crop species and cultivars. Among the wheat family, rye is considered the most Al-tolerant.

In a study of three cereal ryes, three durum wheats and 30 triticales sown in the gravel bed with solutions containing 0, 5, 10, 15, 20 and 40 µL/L of Al, the cereal ryes tested were found to be very tolerant of Al. [71]

5.11 Nutritional deficiencies

To help identify nutritional deficiencies, see the GRDC Winter cereal nutrition: the ute guide.

Making use of the crop nutrition information available to you

As part of the GRDC More Profit from Crop Nutrition (MPCN) extension and training for the southern region project (BWD00021), Birchip Cropping Group (BCG), in conjunction with other grower groups has been hosting nutrition events across the Southern Region since 2012.

Many key nutrition areas are being investigated through the MPCN initiative, however there are a few immediate resources available to advisers to help with understanding nutrition and giving such advice.

Useful resources:

- eXtension Aus—Crop Nutrition: Connecting the lab and the paddock in crop nutrition. This is a group of leading experts in crop nutrition for the Australian grains industry collaborating to provide timely, concise information on crop nutrition issues in Australia. Provides updates on the latest research, and articles focusing on strategic management of crop nutrition in the current season. Twitter account @AuCropNutrition
- BFDC—Better Fertiliser Decisions for Cropping: Fertiliser decisions made by grain growers should all start with, and rely on, knowledge of the fertility status of paddocks. These decisions need to account for the nutrient requirements of plants for growth, nutrient availability in soils, and nutrient losses that can occur during crop growth (e.g. de-nitrification or erosion). BFDC provides the fertiliser industry, agency staff and agribusiness advisors with knowledge and resources to improve nutrient recommendations for optimising crop production. BFDC is recognised by the Fertiliser Industry Federation of Australia as the best available data for supporting the decision tools that fertiliser industry members use to formulate recommendations.
- Nutrition technical workshops are being held by AgCommunicators as part of the GRDC's technical workshop projects. Multiple MPCN projects are being presented at these workshops. Upcoming workshops deal with nitrogen cycling and trace element management and are being held in Bendigo, Ouyen and Murray Bridge
- MPCN—Extension and training for the Southern region.

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70 DAFWA. Diagnosing iron deficiency in wheat. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/mycrop/diagnosing-iron-deficiency-cereals

71 B Scott B (1981) Species and varieties for acid soils. Riverina Outlook Conference, http://www.regional.org.au/au/roc/1981/roc198161.htm

- Events and workshops will continue to be carried out by BCG and details of these events will be available on the BCG website, or will be promoted directly within the area that the event will be held with the help of local grower groups and advisors. This project will also be contributing to crop nutrition publications and extend timely articles and communications in various cropping publications throughout the region. [72]

72 A Elliott (2016) Making use of the crop nutrition information available to you. GRDC Update Papers, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Making-use-of-the-crop-nutrition-information-available-to-you

Weed control

Key messages

- Cereal rye is extremely competitive and has an aggressive root system, so it competes well against weeds. [1]
- Because cereal rye matures earlier than other cereal crops, strict harvest and grazing-management procedures are important to prevent it from becoming a weed. [2]
- Consider Integrated Weed Management (IWM) practices when controlling weeds.
- When selecting a herbicide, it is important to know the crop growth stage, weeds present and plant-back period. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur.
- Check product labels for up-to-date registrations and application methods.
- Use practices that minimise the risk of development of herbicide resistance.

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

Photo 1: *Annual ryegrass (Lolium rigidum) is one of the most problematic weeds in Australia (left).*

Source: FarmPress

6.1 Cereal rye: a weed suppressor

Rye is one of the best cool-season crops for outcompeting weeds, especially small-seeded, light-sensitive annuals (Photo 2). Weed biomass has been found to decrease with increasing rye residue, with weeds completely suppressed at residue levels over 1500 g per m^2. [3] Rye can effectively suppress weeds by shading, competition and allelopathy.

Based on research from southern New South Wales, the competitiveness of crops against annual ryegrass populations at 300 plants per m^2 was in the order oats > cereal rye > triticale > oilseed rape > barley > wheat > field pea > lupin. [4]

1 UVM Extension Crops & Soils Team (2011) Cereal rye. Northern Grain Growers Association, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

2 Atlas of Living Australia. Ryecorn, http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2905471

3 MR Ryan, SB Mirsky, DA Mortensen, JR Teasdale, WS Curran (2011) Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. *Weed Science* 59, 238–246.

4 D Lemerle, B Verbeek, N Coombes (1995) Losses in grain yield of winter crops from *Lolium rigidum* competition depend on crop species, cultivar and season. *Weed Research* 35, 503–509.

Photo 2: *Weed-free cereal rye paddock in Mallee trials.*

Source: Agronomy Matters

IN FOCUS

Rye residues contribute weed suppression in no-tillage cropping systems

The use of allelopathic cover crops in reduced-tillage cropping systems may provide an ecologically sound and environmentally safe management strategy for weed control. Growers often plant winter rye for increased soil organic matter and soil protection. In a study in the United States, spring-planted living rye reduced weed biomass by 93% compared with plots without rye. Residues of autumn-planted–spring-killed rye reduced total weed biomass compared with bare-ground controls. Rye residues also reduced total weed biomass by 63% when poplar excelsior was used as a control for the mulch effect, suggesting that allelopathy, in addition to the physical effects of the mulch, did contribute to weed control in these systems. In greenhouse studies, rye root leachates reduced tomato dry weight by 25–30%, which is additional evidence that rye is allelopathic to other plant species. [5]

6.1.1 Allelopathic effects

Cereal rye produces several compounds in its tissues and releases root exudates that apparently inhibit germination and growth of weed seeds. These allelopathic effects, together with cereal rye's ability to smother other plants with cool weather growth, make it a good choice for weed control (Photo 3).

However, allelopathic compounds may also suppress germination of small-seeded vegetable crops as well if they are planted shortly after the incorporation of cereal rye residue. Large-seeded crops and transplants rarely are affected. There is some

5 JP Barnes, AR Putnam (1983) Rye residues contribute weed suppression in no-tillage cropping systems. *Journal of Chemical Ecology* 9, 1045–1057. doi:10.1007/BF00982210

evidence that the amount of allelopathic compounds in tillering plants is lower than in seedlings. [6]

Photo 3: *Field trial on allelopathic cover crops preceding a tomato crop in a biological farm. Left panel: Plot with rye mulch left on the soil surface, showing the good weed suppression ability. Right panel: Control plot without cover crop, split in two treatments: left side, untreated subplot in which tomato plants are almost completely overgrown by weeds; right side, subplot with mechanical control by cultivations.* [7]

Source: Schulz et al. 2013

The allelopathic effects of rye have been shown in field and laboratory studies to inhibit germination of some triazine-resistant weeds (barnyard grass, willow herb, horseweed). [8]

Rye was also found to reduce total weed density by an average of 78% when rye residue covered more than 90% of soil in a no-till study in Maryland, United States. [9]

Growers can increase rye's weed-suppressing effect by planting rye with an annual legume. However, do not expect complete weed control, and complement with weed-management measures. Thick stands ensure excellent weed suppression. To extend rye's weed-management benefits of the rye, allow its allelopathic effects to persist longer by leaving killed residue on the surface rather than incorporating it. Allelopathic effects usually taper off after about 30 days.

After killing rye, wait three–four weeks before planting small-seeded crops. Rye seedlings have a greater quantity of allelopathic compounds than more mature rye residue. Allelopathic effects usually lasting about 30 days. Transplanted vegetables and larger seeded species, especially legumes are less susceptible to the allelopathic effects of rye. In one study, use of a mechanical under-cutter to sever roots when rye was at mid–late bloom, and leaving residue intact on the soil surface (as whole plants), increased weed suppression compared with incorporation or mowing.

If weed suppression is an important objective when planting a rye–legume mixture, plant early enough for the legume to establish well. If not, a pure stand is likely to work better. [10]

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6 V Grubinger (2010) Winter rye: A reliable cover crop, https://www.uvm.edu/vtvegandberry/factsheets/winterrye.html

7 M Schulz, A Marocco, V Tabaglio, FA Macias, JM Molinillo (2013) Benzoxazinoids in rye allelopathy—from discovery to application in sustainable weed control and organic farming. *Journal of Chemical Ecology* 39, 154–174.

8 T Przepiorkowski, SF Gorski (1994) Influence of rye (Secale cereale) plant residues on germination and growth of three triazine-resistant and susceptible weeds. *Weed Technology* 8, 744–747, https://www.jstor.org/stable/3988190?seq=1#page_scan_tab_contents

9 JR Teasdale, CE Beste, WE Potts (1991) Response of weeds to tillage and cover crop residue. *Weed Science* 39, 195–199, http://www.jstor.org/stable/4044915?seq=1#page_scan_tab_contents

10 A Clark (Ed.) (2007) Managing cover crops profitably. 3rd edn. SARE Outreach Handbook Series Book 9. National Agricultural Laboratory, http://www.sare.org/publications/covercrops.htm

CASE STUDY

Managing land classes for better feed utilisation

Location: Midgee, north of Cowell, South Australia.

Aim: to increase soil cover for erosion protection on the site by fencing off the sandy rises to help manage grazing and establish an appropriate perennial pasture.

Because of the high risk of unfavourable conditions for pasture establishment on this site, perennial veldt grass was established over a two-year period. The paddock had been planted to wheat in 2010 and was left as a ley pasture paddock with summer weeds dominating during 2011.

In June, half of the paddock was sown with a mixture of Bevy cereal rye (20 kg/ha) and veldt grass (2 kg/ha) at 22.5 cm row spacings with 40 kg/ha of 18:20 fertiliser using a disc air-seeder and press-wheels. The remainder of the paddock was sown to 60 kg/ha wheat with 55 kg/ha of 18:20. Winter rainfall totaled only 150 mm prior to August and there was no rain received in the six weeks from August. Despite the low rainfall, the cereal rye and wheat grew very well. However, there was a very poor germination of veldt grass and the lack of rain, combined with moisture competition from the cereal rye, resulted in poor growth.

At harvest the wheat yield averaged 1.1 t/ha, and despite the low cereal rye seeding rate, it yielded ~0.6 t/ha (64 t of which was sold at $282/t).

Despite competition for moisture from the cereal rye, a surprising amount of grass had survived. However, this was mostly in the areas that only had a low density of cereal rye. The plants that were present were very small and had suffered obvious moisture stress.

What problems were encountered?

The main problem was the limited establishment of perennial veldt grass. Although the cereal rye provided good protection for the soil against wind erosion, it was highly competitive. Where the cereal rye was the thickest; there was little or no veldt grass.

Actively growing cereal rye competed vigorously with the veldt grass for moisture. To minimise this competition it may be feasible to sow veldt grass into standing stubble, or if there is no stubble on the paddock, only sow the cover crop with a very light seeding rate (10 kg/ha) so the paddock is protected from wind erosion without the competition for moisture during the veldt grass establishment. [11]

11 Natural Resources SA (2014) Producer case study. Managing land classes for better feed utilisation. Natural Resources SA, http://www.naturalresources.sa.gov.au/files/e7e04254-1bae-4763-9400-a38700980519/managing-land-classes-for-better-feed-utilisation-walsh-case-study-gen.pdf

Remove cereal rye early to avoid problems from its allelopathic effect

The decaying green substance ('ooze') from cereal rye, rather than the herbicide used to kill the rye, can create problems for germinating grasses (e.g. maize) (Photo 4). This toxic effect of the dying rye makes it a good cover-crop choice for organic producers. A good rye stand reduces weed problems while it is growing. Producers then roll down the rye to terminate it (no herbicide is used) and then plant their broadleaf crop. The decaying rye affects the germinating grasses, greatly reducing grass weed pressure while the crop is becoming established. The cover provided by the rye also reduces weed pressure by providing a mulch and by keeping the sun off the soil surface until the crop canopy forms.

When using a cereal rye cover crop in a no-till situation, it is preferable to spray out the rye two–three weeks before planting maize, so that the rye is brown before planting. Rye should not be sprayed out five–ten days before planting, assuming glyphosate is being used, because the rye will be decaying as the maize is germinating. For a shorter window before spraying and planting, use a different herbicide to kill the cereal rye more quickly so that it is dead and brown sooner.

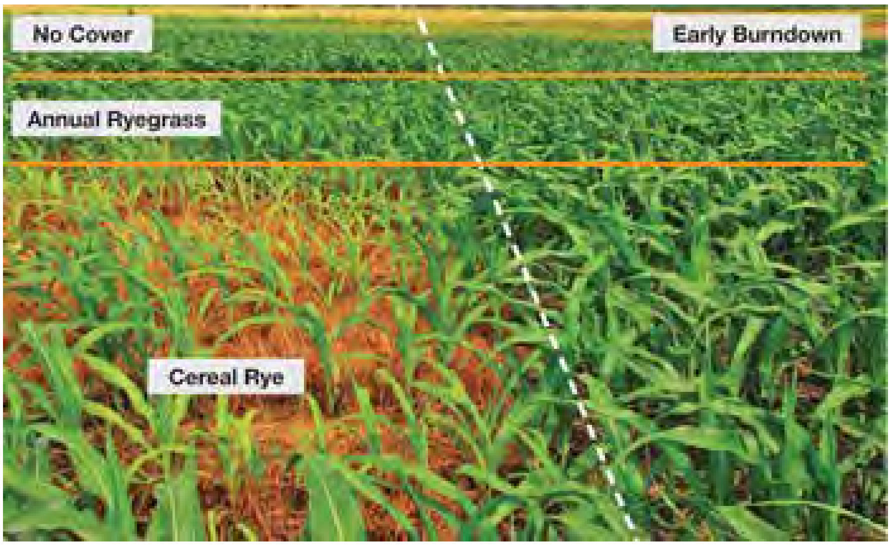


Photo 4: *Effects of a late kill of cereal rye on maize plants. The impact appears to be from a combination of the carbon penalty and allelopathy exerted by the cereal rye.*

Source: AgWeb

Some producers say that germination problems are minimal if there is no rain to leach the substance down to the germinating seed during this establishment time. Others report that the germination problems can be reduced by planting deeper. [12]

6.1.2 Volunteer rye

Volunteer rye may contaminate wheat, oats and barley. [13]

Rye is not always a tall, robust plant, and under stressful conditions, such as those found in tilled and chemical fallow fields, grassy field edges and roadsides, it can still grow and produce seed despite only attaining heights of less than 25 cm (Photo 5).

12 P Jasa P (2012) Kill rye early to avoid problems from its allelopathic effects. Cropwatch. University of Nebraska, http://cropwatch.unl.edu/kill-cereal-rye-early-avoid-problems-its-allelopathic-effect

13 Manure $ense (2009) Cereal rye: Manure and livestock's new best friend. Midwest Cover Crops Council, http://mccc.msu.edu/wp-content/uploads/2016/09/MI_2009_CerealRyeManure.pdf

Photo 5: *Shorter stands of cereal rye can still produce seed heads.*

Source: NebGuide

Preventative methods are a critical part of an IWM control system for volunteer rye. Eliminating potential seed sources for rye establishment is a priority.

To eliminate seed sources:

1. Plant clean seed. Volunteer rye seed is often found in cereal seed, especially winter wheat. It is difficult to separate volunteer rye seed from winter wheat seed; therefore, growers should be aware of their winter wheat seed source or buy only certified seed.
2. Destroy any volunteer rye before it produces seed. Rye may germinate as late as mid-April and still experience sufficient cold weather to vernalise and produce seed. Rye plants as short as 20 cm can produce viable seed.
3. Thoroughly clean combines before moving between paddocks.
4. Make sure that all rye is kept out of roadside ditches and other areas that may contaminate the fields. This task may be aided by covering all trucks transporting winter wheat grain.

Burning frequently results in soil erosion and has other adverse environmental impacts. Also, fire is usually not hot enough to kill a high percentage of volunteer rye seed. The amount of crop residue, the temperature, and the length of burn greatly limit fire as a potential weed-control method. [14]

Growers can improve winter wheat's competitiveness with volunteer rye by using cultural practices that stimulate rapid emergence and vigorous seedling growth. For example, deep-banding of nitrogen (N) fertiliser near wheat seeds at planting, planting larger sized wheat seeds, increasing wheat seeding rates, reducing wheat-row spacing, and planting taller wheat cultivars that tiller profusely are all cultural practices that have been reported to improve wheat's competitiveness with weeds.

Tillage or chemical control of volunteer rye during the fallow period can reduce subsequent populations in the winter wheat crop similarly over a two-year period.

Post-emergence, non-selective herbicides such as glyphosate or paraquat can control volunteer rye and other winter annual grasses found in fallow fields. Glyphosate and paraquat do not provide residual weed control; therefore, any volunteer rye plants that emerge after treatment will not be controlled. Both of these herbicides are inactivated on contact with soil, meaning that all weed plants should

14 D Lyon, R Klein (2014) Rye control in winter wheat. University of Nebraska Extension, https://web.archive.org/web/20140413144910/http://www.ianrpubs.unl.edu/pages/publicationD.jsp?publicationId=106

be emerged prior to application. The effectiveness of both herbicides on volunteer rye decreases as plant size and maturity increase. Glyphosate is labelled for volunteer rye control in wheat as a wiper application. This technique requires at least a 25-cm height differential between the wheat and volunteer rye. Care must be taken to prevent any herbicide from contacting the wheat. Any herbicide that drops on or otherwise contacts wheat will result in death. [15]

6.2 Integrated weed management

The Grains Research and Development Corporation (GRDC) supports IWM, which is a system for managing weeds over the long term, particularly the management and minimisation of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given the additional costs associated with implementing IWM, the main issues for growers are whether it is cost-effective to adopt the system and whether the benefits are likely to be long-term or short-term in nature.

Download the Integrated Weed Management Manual.

The IWM manual examines these issues and breaks them down into seven clear sections, assisting the grower in the development of an IWM plan.

Effective strategic and tactical options are available to manage weed competition that will increase crop yields and profitability. Weeds with herbicide resistance are an increasing problem in grain cropping enterprises. Industry and researchers advise that growers adopt IWM to reduce the damage caused by herbicide-resistant weeds.

The following five-point plan will assist in developing a management strategy in each paddock:

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

An integrated weed management plan should be developed for each paddock or management zone.

In an IWM plan, each target weed is attacked by using tools from several tactic groups (see links below). Each tactic provides a key opportunity for weed control and is dependent on the management objectives and the stage of growth of the target weed. Integrating tactic groups reduces weed numbers, stops replenishment of the seedbank and minimises the risk of developing herbicide-resistant weeds.

IWM tactic groups:

- Reduce weed seed numbers in the soil
- Control small weeds
- Stop weed seedset
- Practice hygiene—prevent weed seed introduction
- Use agronomic practices and crop competition

Successful weed management also relies on the implementation of best agronomic practices to optimise crop growth. Basic agronomy and fine-tuning of the crop system are the important steps towards weed management.

Several agronomic practices can improve crop environment and growth, along with the crop's ability to reduce weed competition. These include crop choice and

15 S Miller, C Alford, W Stump. Feral rye: A serious threat to high quality wheat. University of Wyoming Extension, http://www.wyoextension.org/agpubs/pubs/B1157.pdf

sequence, improving crop competition, planting herbicide-tolerant crops, improving pasture competition, and using fallow phases and controlled traffic or tramlining. [16]

6.2.1 Five-point plan

1. Review past actions

Knowledge of the historical level of selection pressure can be valuable information to predict which weeds or Mode-of-Action (MoA) groups are at greatest risk in terms of resistance development. Such knowledge can prompt more intensive monitoring for weed escapes when a situation of higher risk exists. Picking up newly developing resistance issues while patches are still small, before they spread, can make a big difference to the cost of management over time.

From all available paddock records, calculate or estimate the number of years in which different herbicide MoAs have been used. The number of years in which a herbicide MoA has been used is of far greater relevance than the total number of applications. For most weeds, use of a herbicide MoA in two consecutive years presents a far greater selection pressure for resistance than two applications of the same herbicide MoA in the one year. If the entire paddock history is unavailable, record what is known and estimate the rest. Collate separate data on MoA use for summer and winter weed spectrums. Further subdivide these into broadleaf and grass weeds.

Account for double-knocks. Where survivors of the first tactic would have been largely controlled by the second tactic, reduce the number of MoA uses accordingly. For example, trifluralin (Group D) may have been used 20 times, but during six years, in-crop Group A selectives were used, and during several more years, in-crop Group B products targeting the same weed as the trifluralin were used. These in-crop herbicides effectively double-knocked the trifluralin, thus somewhat reducing the effective selection pressure for resistance to trifluralin.

Review the data you have collected and identify which weeds and MoA groups have been selected for at a frequency likely to lead to resistance in the absence of a double-knock. Trifluralin typically takes about 10–15 years of selection for resistance to occur (Table 1). Thus in the above example, a 'watching brief' would be in place for trifluralin and other Group D MoA herbicides.

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

Information on history of MoA use should be added to paddock records.

Table 1: *Typical number of years of use to develop resistance to Mode-of-Action (MoA) groups.*

MoA Group	Typical years of application	Resistance risk
A (fops, dims, dens)	6–8	High
B (SUs, IMIs)	4	High
C (triazines, subst. ureas)	10–15	Medium
D (trifluralin, Stomp®)	10–15	Medium
F (diflufenican)	10	Medium
I (phenoxies)	>15	Medium
L (paraquat, diquat)	>15	Medium
M (glyphosate)	>12	Medium

16 DAFWA (2016) Crop weeds: Integrated Weed Management (IWM). Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm

2. Assess the current weed status

Record the key broadleaf and grass weed species for summer and winter and include an assessment of weed density, with notes on weed distribution across the paddock. Include GPS locations or reference to spatial location of any key weed patches or areas tested for resistance.

Include any data, observations or information relating to the known or suspected herbicide-resistance status of weeds in this paddock.

Grass weed seeds can be submitted for herbicide resistance testing against the range of herbicides and herbicide groups. Growers can register and submit samples to Plant Science Consulting (all sampling information and instructions are available on the website). Growers should consider spending 1–2% of the chemical budget on herbicide resistance testing.

Add all of this this information to paddock records.

3. Identify weed management opportunities within the cropping system

Identify which different herbicide and non-herbicide tactics could be cost-effectively added to the system and where in the crop sequence these can be added. For information on the different integrated weed management tactics, see IWM: Section 4: Tactics for managing weed populations.

4. Fine-tune your list of options

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

5. Combine and test ideas

Computer-simulation tools can be useful to run a number of scenarios to investigate potential changes in management and the likely effect of weed numbers and crop yield. Two simulation tools being used are the Weed Seed Wizard and RIM—Ryegrass Integrated Management.

Combine ideas by using a rotational planner, or test them by using decision support software such as RIM and/or Weed Seed Wizard.

Weed Seed Wizard

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

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

The Wizard uses farm-specific information, and users enter their own farm-management records, paddock soil type, local weather and one or more weed species. The Wizard has numerous weed species to choose from including annual ryegrass, barley grass, wild radish, wild oat, brome grass and silver grass in the southern states, and liverseed grass, barnyard grass, paradoxa grass, feathertop Rhodes grass, bladder ketmia, fleabane, sowthistle, sweet summer grass, cowvine, and bellvine in the north.

MORE INFORMATION

Weed seed wizard

Ryegrass integrated management

RIM provides insights into the long-term management of annual ryegrass in dryland broadacre crops facing development of herbicide resistance. RIM enables alternative strategies and tactics for ryegrass management to be compared for profit over time and impact on weed numbers. The software's underlying model integrates biological, agronomic and economic considerations in a dynamic and user-friendly framework, at paddock scale and over the short and long term.

The tool tracks the changes through time on a 10-year crop cycle for ryegrass seed germination, seed production and competition with the crop. Financial returns are also estimated annually and as a 10-year average return.

RIM allows you to try out many different combinations of weed treatments and observe their predicted impacts on ryegrass populations, crop yields and long-term economic outcomes. A wide variety of chemical and non-chemical weed treatment options are included, so that as chemicals are lost to herbicide resistance, the next best substitute can be identified.

To do this by trial and error in the real world, rather than in a computer simulation, would take many years and may leave farmers with a major weed problem they could have avoided. With RIM, farmers and others can conduct virtual experiments with a vast range of treatment options before they put real dollars at risk.

RIM can help farmers to tackle questions such as:

- How much income will I lose once resistance develops?
- Which combination of strategies provides the best overall system once resistance is present?
- Is it worth trying to delay the onset of resistance by using herbicides less frequently?
- Is it economically viable to maintain a continuous cropping rotation once resistance is present?
- If a pasture phase is included, how long should it be?

MORE INFORMATION

AHRI: Ryegrass Integrated Management

VIDEOS

WATCH: Managing herbicide resistant ryegrass with IWM.

6.2.2 IWM in the Southern Region

Grain growers in Victoria, South Australia and Tasmania can beat costly weeds by driving down the weed seedbank through an aggressive 'stacked' approach. By combining five essential measures and repeating the exercise year after year, growers can run down seedbanks even when experiencing high levels of herbicide resistance on their farms.

Very high weed seedbanks can be eroded to low, near-zero levels by committing to a simple strategy. The components of a successful strategy are:

1. A double knock of herbicides.
2. Mixing and rotating chemicals.
3. Competitive crops.
4. Stopping seedset.
5. Harvest weed-seed control (HWSC).

Double-knock is not so much about the seedbank but preserving the usefulness of glyphosate. If double-knock is implemented every year, glyphosate resistance should not be an issue. However, if glyphosate resistance is already present and you try to double-knock, you are essentially applying a single knock of paraquat, and then paraquat resistance will arise. The best time to start using a double-knock strategy is before any glyphosate resistance.

It is also important to use herbicide mixtures. If two herbicides are mixed together at full rates, then a weed that is resistant to one product will be killed by the other product before seedset, because it is almost impossible for a weed to have two resistance mechanisms before herbicide selection pressure has occurred.

Crop competition involves four aspects—seeding rate, row spacing, orientation and cultivars. Growers need to adopt appropriate recommendations for at least one (preferably two) of these, in terms of encouraging crop competition.

HWSC has been a focus of research and development efforts of the Australian Herbicide Resistance Initiative (AHRI). Several options are available, depending on the situation:

- In mixed farming systems with sheep, using a chaff cart for HWSC is recommended.
- For continuous croppers in high-production areas, the Harrington Seed Destructor is recommended.
- Putting chaff on tramlines is cheap and there is nothing to do after harvest.
- Chaff-lining is another option, leaving it in the windrow to rot.
- Windrow burning is a popular option, with more people windrow-burning than any other HWSC activity, but it does have issues. The other HWSC tools can be used in every crop every year, but that is not always the case with windrow burning.
- Bale direct involves towing a baler behind the harvester. This is a good option where a large market for straw bales exists close to the farm.

Competitive crops improve HWSC. Competitive crops support the ryegrass and other weeds so that they can be caught in the header. HWSC works better on low-density ryegrass. If the seedbank is low and HWSC is used, it is particularly effective.

Many weeds are becoming more dormant. Later germination, which avoids knock-down and pre-emergent herbicides, is being selected in weeds such as ryegrass, barley and brome grasses. However, it can be an advantage to growers because a competitive crop can be sown early to compete with the weeds.

When all components of weed-seed management are stacked together and growers commit to the regime for at least six years, the outcome can be dramatic. [17]

South Australian Weed Control app

The free South Australian Weed Control app provides essential information about the control of weeds declared in South Australia under the Natural Resources Management Act 2004. It is produced by Biosecurity SA in partnership with the eight Natural Resource Management regions.

The app includes:

- control recommendations for >132 declared plants
- chemical and non-chemical treatments
- information on the safe use of herbicides
- colour photographs of each species for identification.

The app provides information from the Weed Control Handbook for Declared Plants in South Australia.

In addition, app users can:

- record the location of weeds
- keep a personal log of control activities
- phone or email regional Natural Resource officers

17 S Watt (2016) Odds of beating weeds stacked in favour of grain growers. GRDC Media Centre, March 2016, https://grdc.com.au/Media-Centre/Media-News/South/2016/03/Odds-of-beating-weeds-stacked-in-favour-of-grain-growers

MORE INFORMATION

PIRSA: Weed control handbook for declared plants in South Australia.

PIRSA: Declared plants in SA—are they on your land?

PIRSA: SA weed risk management guide.

- send photos and text of high-risk weeds.

The app is updated annually as chemical uses and plant declarations change.

Download app from Google Play (for Android devices) or iTunes App Store.

6.2.3 Cover cropping for weed management

The critical period for weed suppression by the cover crop is typically the first 30 days of cover-crop growth. A cover crop's ability to suppress weeds is generally correlated with the cover crop's early season biomass production rather than its biomass at maturity. Cover crops such as cereal rye maximise light interception with a dense canopy early in the season are the best at suppressing weed growth and weed-seed production (Photo 6). [18]

IN FOCUS

Overcoming weed management challenges in organic rotational no-till soybean production based on cover cropping

Organic rotational no-till soybean production based on cover cropping has attracted attention from farmers, researchers, and other agricultural professionals because of the ability of this system to enhance soil conservation, reduce labor requirements, and decrease diesel fuel use compared to traditional organic production. This system is based on the use of cereal rye cover crops that are mechanically terminated with a roller-crimper to create *in situ* mulch that suppresses weeds and promotes soybean growth. This study reports on experiments conducted in the United States on cover crop-based organic rotational no-till soybean production, and outlines current management strategies and future research needs. The study focused on maximising spring groundcover and biomass of cereal rye because of the crucial role of this cover crop in weed suppression. Soil fertility and timing of cereal rye sowing and termination affect biomass production, and these factors can be manipulated to achieve levels less than 8,000 kg/ha, a threshold identified for consistent suppression of annual weeds. Cereal rye seeding rate and seeding method also influence groundcover and weed suppression. In general, weed suppression is species-specific, with early-emerging summer annual weeds, high weed seedbank densities (e.g. 10,000 seeds/m^2) and perennial weeds posing the greatest challenges. Because of the challenges of maximising the weed-suppression potential of cereal rye, the practice of high-residue cultivation may be an additional means to improve weed control. In addition to cover crop and weed management, progress has been made with planting equipment and planting density for establishing soybean into a thick cover-crop residue. Future research will focus on integrated multi-tactic weed management, cultivar selection, insect pest suppression, and nitrogen management as part of a systems approach to advancing this new production system. [19]

18 R Smith, RL Bugg, M Gaskell, O Daugovish, M Van Horn (Eds) (2011) Cover cropping for vegetable production: a grower's handbook. Publication no. 3517. UCANR Publications.

19 SB Mirsky, MR Ryan, JR Teasdale, WS Curran, CS Reberg-Horton, JT Spargo, JW Moyer (2013) Overcoming weed management challenges in cover crop-based organic rotational no-till soybean production in the Eastern United States. *Weed Technology* 27, 193–203, http://www.bioone.org/doi/abs/10.1614/WT-D-12-00078.1

VIDEOS

WATCH: Over the Fence: IPM delivers 'unexpected' pest control benefits.

Photo 6: *Effect of seeding rate on weed suppression of a 90% legume and 10% cereal rye mixed cover crop. The higher seeding rate (left) was more effective in suppressing weeds than the lower seeding rate (right), which saw the emergence of weeds.* [20]

Source: Smith et al. 2011

Suppression of annual ryegrass by wheat, triticale and rye was compared in field trials at Wagga Wagga, NSW, in 1993. Cereal rye and triticale were more competitive than wheat, with a biomass of annual ryegrass at maturity of 70 g/m^2 with triticale compared with 170 g/m^2 with wheat. Early seedling vigour, superior height and broad leaves appeared to influence the greater competitive ability of triticale and cereal rye. [21]

6.3 Key weeds in Australia's cropping systems

Click on the weed name below to view 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*)

Paradoxa grass (*Phalaris paradoxa*)

Silver grass (*Vulpia* spp.)

Sweet summer grass (*Brachiaria eruciformis*)

Turnip weed (*Rapistrum rugosum*)

Wild oats (*Avena fatua, and A. ludoviciana*)

20 R Smith, RL Bugg, M Gaskell, O Daugovish, M Van Horn (Eds) (2011) Cover cropping for vegetable production: a grower's handbook. Publication no. 3517. UCANR Publications.

21 D Lemerle, K Cooper (1996) Comparative weed suppression by triticale, cereal rye and wheat. In Triticale: Today and tomorrow. pp. 749–750. Springer Netherlands.

Wild radish (*Raphanus raphanistrum*)

Windmill grass (*Chloris truncata*)

Wire weed (*Polygonum aviculare, P. arenastrum*) [22]

6.3.1 Annual ryegrass management in the Southern Region

South Australian trial

Herbicide resistance in annual ryegrass is on the increase, with higher levels of chemical tolerance recorded in the south-east of South Australia. A survey in 2013 found that 16% of paddocks in the region contained glyphosate-resistant ryegrass (Photo 7).

Photo 7: *Glyphosate-resistant ryegrass in a crop paddock.*

Source: Weekly Times

A three-year trial by the University of Adelaide at Roseworthy, in South Australia's mid-north, found that strategic use of oaten hay was the best tool for rapidly reducing the seedbank of annual ryegrass. However, another year of seedset control is vital for keeping populations low.

Three weed-management strategies were used for ryegrass control in a four-year trial. Cutting oaten hay in the first year reduced the seedbank of ryegrass by 86%, from 4819 to 692 seeds/m^2 in one year. Field peas were sown in the following year and three spray options used across three sections.

- When trifluralin was used alone, seedbank levels increased from 692 to 8319 seeds/m^2.
- When Select® (clethodim) was applied after trifluralin, the ryegrass seedbank slightly increased from 692 to 806 seeds/m^2.
- When Select® was applied and the field peas were crop-topped with Roundup® (glyphosate), the seedbank declined to less than 500 seeds/m^2.

This shows the importance of a second year of seedset control in managing annual ryegrass.

Growers should be cautious about chemical use because resistance to Select® is on the increase in South Australia—a major concern given the herbicide's importance for providing effective control of ryegrass in pulse and canola break crops.

Crop-topping after Select® application, even if there are only a few weeds left in the paddock, decreased the risk of resistance emerging.

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

Where two years of seedset control had been used, the annual ryegrass seedbank in the following wheat crop continued to decline, even where Boxer Gold® was the only herbicide used. [23]

Victorian trial

From 2012, a trial at Southern Farming Systems' Lake Bolac site, which has a history of resistant annual ryegrass, assessed the effectiveness and applicability of cultural control practices before seeding, in combination with pre-emergent herbicides, on management of herbicide-resistant annual ryegrass in the Victorian high-rainfall zone (HRZ).

The cultural control practices included mouldboard ploughing, stubble burning, stubble incorporation with light cultivation and retained stubble with direct sowing. These were followed up with pre-emergent options of low cost (such as trifluralin mixtures), or medium and high cost (such as Sakura® (pyroxasulfone) + Avadex® Xtra (triallate) mixtures in wheat).

Mouldboard ploughing

Although mouldboard ploughing is expensive, early results were promising, despite some wild radish germinating in the ploughed area. In a long-season scenario where there is plenty of rain, any ryegrass that germinates late, after treatments have been applied, will produce a great deal of seed. In the HRZ, this is a problem. If growers do not stop ryegrass seedset, it will quickly replenish the seedbank.

Pre-emergent herbicides

If using pre-emergent herbicides, stubble should not be burnt rather than incorporated. Incorporating stubble moves the ryegrass away from the herbicides, limiting their effectiveness.

If post-emergent resistant ryegrass is present, growing wheat and barley is not an effective management option. Even with the best treatments, resistant ryegrass numbers are still increasing.

The cheapest pre-emergent herbicide strategies were the least effective. The mid-cost strategy was better and the expensive strategy best.

To contain the ryegrass in the cereal part of the rotation in the HRZ, more expensive herbicide options are needed to achieve length of persistence, such as the Sakura® + Avadex® Xtra mix.

Narrow windrow burning

When attempting to windrow-burn barley in these trials, the burn was too fast and did not burn the windrows all the way down to the ground, leaving streaks of ryegrass across the site. Barley may be the most difficult crop for windrow burning. [24]

6.3.2 Brome grass and barley grass in the Southern Region

Increasing incidence of brome grass and barley grass in cropping paddocks in southern Australia is likely to be associated with selection of more dormant biotypes because of weed-management practices used by growers.

Brome grass

Control of brome grass is becoming increasingly difficult throughout south-eastern Australia's cropping zone owing to high levels of herbicide resistance, increasing seed dormancy, and spread of the weed from its traditional low-rainfall area to other regions (Photo 8).

23 D Lush (2013) Consistent weed control needed to combat ryegrass. GRDC Ground Cover Issue 106, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-106-Sept-Oct-2013/Consistent-seed-control-needed-to-combat-ryegrass

24 A Lawson (2015) HRZ trial yields lessons in resistant ryegrass management. GRDC Media Centre, January 2015, https://grdc.com.au/Media-Centre/Media-News/South/2015/01/HRZ-trial-yields-lessons-in-resistant-ryegrass-management

Currently, brome grass management in cereals relies heavily on Group B herbicides, especially the ClearfieldTM technology. Delaying onset of resistance to these herbicides will require identification of effective alternative herbicides.

Photo 8: *Brome grass growing in a cereal crop at a University of Adelaide trial, Balaklava, South Australia.*

Source: GRDC

Field trials undertaken over four years have investigated various pre-emergence herbicides for brome grass control in wheat. Although Sakura® seems the most active pre-emergent herbicide against brome grass, it lacks the consistency required for long-term population management.

Surveys by the University of Adelaide in an earlier GRDC-funded project showed high levels of resistance to Group B herbicides, with 40–50% resistance to Atlantis® (mesosulfuron-methyl) and CrusaderTM (pyroxsulam) in the South Australian Mallee, and 40% resistance to Atlantis® in Victoria.

Pre-emergent control options are no more promising because most common options are ineffective. The most common practice in wheat is use of trifluralin, but these trials have shown that trifluralin may provide only ~50% control in wheat. The combination of Sakura® and Avadex® has been shown to be more effective, but the high cost means that it is often uneconomical.

With herbicide control providing no easy solutions, an IWM strategy is needed to control the problem weed. Where there are severe brome patches in cereals, >50 plants/m^2, it is recommended that growers patch out the area with a knockdown herbicide such as glyphosate before it can set seed. Where the soil type permits, narrow windrow burning can be a good control method, or options such as chaff carts can help reduce the seedbank.

However, the most effective control will be achieved through use of rotations. For a severe infestation, use a pulse or break crop with a grass-selective herbicide and crop-topping, followed by a ClearfieldTM variety using imidazolinone ('imi') chemistry. If there are still some weeds after two years, proceed to barley with trifluralin and metribuzin for a third-step control.

MORE INFORMATION

GRDC Update papers: Brome and barley grass management in cropping systems of southern Australia

GRDC Media: Long-term strategy needed for brome grass control

Full results from the trials are expected in 2017. [25]

Barley grass

Field trials confirmed consistently high efficacy of Sakura® against barley grass, especially in situations with good soil moisture. Barley grass management is becoming complicated by evolution of Group A resistance in this species. However, several effective alternatives (e.g. Sakura® and Raptor® (imazamox)) could likely be used for barley grass control in broadleaf crops. [26]

Barley grasses are annual species renowned for rapidly germinating in autumn to provide valuable stock feed soon after breaking rain (Photo 9). This speedy establishment has traditionally been seen as a useful clue for early identification, but changes in seedbank dormancy now mean an increasing proportion of the seedbank germinates later in the season.

Photo 9: *Seedling of barley grass (*Hordeum leporinum*) (Photo D. Holding).*

Source: GRDC

Barley grass is a problem for several reasons:

- It acts as an alternative host for a number of cereal diseases.
- Seeds of barley grasses cause stock health problems.
- Post-emergent herbicide control is limited in cereals.
- Barley grasses are readily dispersed.
- Populations of barley grasses can develop resistance to herbicides. [27]

6.3.3 Emerging flaxleaf fleabane threat

Flaxleaf fleabane (Photo 10) is a major weed in dryland crops in southern Queensland and northern New South Wales, and it is emerging as a problem weed across the entire cereal-cropping belt of southern Australia.

25 R Barr (2014) Long-term strategy needed for brome grass control. GRDC Media Centre, October 2014, https://grdc.com.au/Media-Centre/Media-News/South/2014/10/Long-term-strategy-needed-for-brome-grass-control

26 G Gill, L Shergill, B Fleet, P Boutsalis, C Preston (2013) Brome and barley grass management in cropping systems of southern Australia. GRDC Update Papers, February 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Brome-and-barley-grass-management-in-cropping-systems-of-southern-Australia

27 GRDC (2014). Section 8. Profile of common weeds of cropping. Barley grass. Integrated weed management manual. GRDC Integrated Weed Management Hub, https://grdc.com.au/Resources/IWMhub/Section-8-Profiles-of-common-weeds-of-cropping/Barley-grass

Photo 10: *Flaxleaf fleabane.*

Source: GRDC

Previously, fleabane was found mainly on roadsides, particularly where council use of glyphosate created bare ground on which the weed could flourish without competition. However, the weed is highly mobile and soon found its way into adjacent cropping systems.

With the change to minimum tillage and the increasing use of glyphosate, the scene was set for an expansion of this troublesome weed. Wet summers in southern grain regions over the past two years have aided the weed's spread.

Fallow weed control costs have increased markedly because of fleabane, with some no-till growers having to reintroduce cultivation as a last-resort control tactic. Disturbingly, populations of fleabane have recently been confirmed as resistant to eight times the normal rate of glyphosate, earning fleabane the title of Australia's first glyphosate-resistant broadleaf weed.

Control strategy

Although fleabane presents a serious and costly weed challenge, GRDC-funded research has shown that a strategic approach using IWM can significantly reduce the weed's impact on crop production.

The key to controlling fleabane is to attack all parts of the weed's life cycle to keep the seedbank low. An IWM strategy including chemical and non-chemical tactics will result in substantially reduced fleabane problems and fewer resistant populations in subsequent seasons.

Fleabane has the capacity to produce two or three generations each year and 110,000 seeds per plant, so control before it sets seed is critical.

In southern areas and in Western Australia, fleabane often germinates under crops during spring or at harvest. Following harvest, a lack of crop competition combined with summer rain can cause rapid weed growth. By the time there is a window for control, the fleabane plants are often mature, with a large root system, reduced leaf area and high tolerance to most herbicides.

Research across Australia indicates that hitting the weed with herbicide while it is young and actively growing is the best approach. Conversely, delaying herbicide application until the weed is mature and water-stressed can result in poor control.

MORE INFORMATION

GRDC Fact Sheet: Managing Flaxleaf fleabane

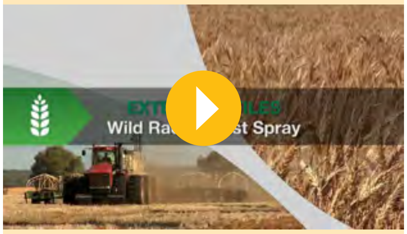
Northern IWM Fact Sheet: Flaxleaf fleabane: a weed best management guide

VIDEOS

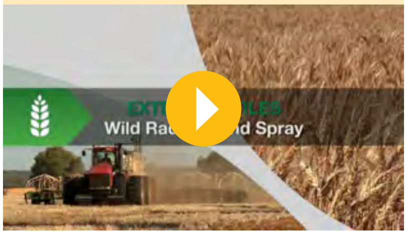
WATCH: GCTV4: Flaxleaf fleabane.

WATCH: GCTV14: Early control wild radish.

WATCH: GCTV Extension files: Wild Radish – 1st spray.



WATCH: GCTV Extension files: Wild radish – 2nd spray.



The double-knock approach, with glyphosate followed by paraquat, has proved a critical component of a fleabane IWM program. This approach, coupled with the use of competitive crops and pastures and strategic cultivations to bury blowouts of seed production, can reduce the weed seedbank to manageable levels within a few seasons. It is also important to target fencelines and roadsides. [28]

6.3.4 Wild radish herbicide resistance

Growers in the GRDC's Southern Region should be able to draw on the experience of their western counterparts for developing and implementing proactive control strategies for herbicide-resistant wild radish. Herbicide-resistant wild radish (Photo 11) is becoming a serious threat in the region, but growers in the west have considerable experience keeping this difficult weed in check.

Photo 11: *Herbicide-resistant wild radish plant in cereal paddock.*

Source: DAFWA

Although wild radish has been present in both regions, the use of a sheep–wheat rotation in southern New South Wales, Victoria, South Australia and Tasmania has helped to keep the weed under control.

By contrast, Western Australia's intensive cropping system has led to wild radish becoming the number one weed issue, with 60% of wild radish populations developing resistance to some herbicide. Some populations are now resistant to multiple herbicide groups.

The number of resistant wild radish populations in the Southern Region is still significantly lower than in the west; however, enterprise changes are beginning to replicate what has happened in Western Australia, with growers moving towards a more intensive cropping system with fewer sheep and more herbicide applications.

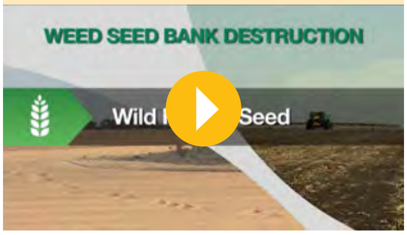
According to University of Adelaide weed scientist Dr Christopher Preston, in 2013 there were more than 20 paddocks across Victoria and South Australia with wild radish resistant to herbicides. Of these, five populations were resistant to Group I herbicides (three in Victoria and two in South Australia) and one was resistant to Group B, Group I and Group F.

28 M Widderick (2013) Fleabane now a national challenge. GRDC Ground Cover Issue 102, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102/Fleabane-now-a-national-challenge

VIDEOS

WATCH: GRDC Grains Research Updates 6-7 February 2013, Southern Region, Ballarat VIC. Bill Campbell

WATCH: IWM: Weed seed bank destruction – wild radish seed.



MORE INFORMATION

WeedSmart: Herbicide resistant wild radish: take back control.

GRDC Fact Sheet: Wild radish management and strategies to address herbicide resistance

Dr Peter Boutsalis is director of Plant Science Consulting, which carries out annual herbicide-resistance testing on wild radish from paddocks where herbicides have failed. Since 2009, half of the 60 wild radish samples received from growers across south-eastern Australia have been verified as resistant to Group B and Group I herbicides. When poor herbicide control of wild radish is identified, it is critical that the weed seed is tested for herbicide resistance.

GRDC-funded research across the Western and Southern regions has been quantifying the extent of the wild radish problem and developing management systems to lower the weed's on-farm seedbank.

Over the past decade, research by Professor Stephen Powles and his team at AHRI has unravelled the biology of wild radish and has developed innovative control strategies.

An underlying principle of wild radish management is to keep the weed seedbank in check. More than 90% of seed can be captured at harvest. As long as this seed is destroyed or removed via chaff carts, baling systems, windrowing and subsequent burning, crushing (via the Harrington Seed Destructor) or feeding to livestock, then radish seedbank numbers can be reduced to manageable levels.

When weed seed is not destroyed, it remains in the chaff to be spread back onto the paddock or, worse still, to be transported to another paddock, where wild radish or herbicide-resistant wild radish may not be present. [29]

6.4 Herbicides explained

When selecting a herbicide, it is important to know crop growth stage, weeds present and plant-back period. For best results, weeds should be sprayed while they are small and actively growing. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur. Check product labels for up-to-date registrations and application methods.

6.4.1 Residual and non-residual

Residual herbicides remain active in the soil for an extended period (months) and can act on successive weed germinations. Residual herbicides are absorbed through the roots or shoots, or both. Examples of residual herbicides include imazapyr, chlorsulfuron, atrazine and simazine.

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. Persistence of herbicides will affect the sequence chosen (a rotation of crops, e.g. wheat–barley–chickpeas–canola–wheat).

Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and they are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

6.4.2 Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, whereas pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. [30]

29 J Paterson J (2013) South faces wild radish resistance. GRDC Ground Cover Issue 102, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102/South-faces-wild-radish-resistance

30 GRDC Integrated weed management, Section 4: Tactics for managing weed populations, http://www.grdc.com.au/~/media/A4C48127FF8A4B0CA7DFD67547A5B716.pdf

Herbicides are classified into a number of groups, which refers to the way a chemical works—their different chemical make-up and MoA (Table 2). [31]

Table 2: *Herbicide Mode of Action groups and examples of chemicals and proprietary products in each group.*

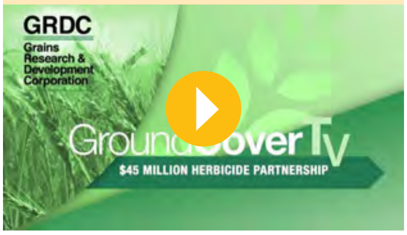
Group A	Hoegrass®, Nugrass®, Digrass®, Verdict®, Targa®, Fusilade®, Puma S®, Tristar®, Correct®, Sertin® Grasp®, Select®, Achieve®, Gallant®, Topik®
Group B	Glean®, chlorsulfuron, Siege®, Tackle®, Ally®, Associate®, Logran®, Nugran®, Amber Post® Londax®, Spinnaker®, Broadstrike®, Eclipse®, Renovate®
Group C	Simazine, atrazine, Bladex®, Igran®, metribuzin, diuron, linuron, Tribunil®, bromoxynil, Jaguar®, Tough®
Group D	Trifluralin, Stomp®, Yield®, Surflan®
Group E	Avadex®, BW, EPTC, chlorpropham
Group F	Brodal®, Tigrex®, Jaguar®
Group H	Saturn®
Group I	2,4-D, MCPA, 2,4-DB, dicamba, Tordon®, Lontrel®, Starane®, Garlon®, Baton®, Butress®, Trifolamine®
Group K	Dual®, Kerb®, Mataven®
Group L	Reglone®, Gramoxone®, Nuquat®, Spraytop®, Sprayseed®
Group M	Glyphosate, Glyphosate CT®, Sprayseed®, Roundup CT®, Touchdown®, Pacer®, Weedmaster®

List of commonly used products only. Listing of products does not necessarily imply state registration. Check that product is registered in your state before use. Groups G and J not included.

Source: DPI NSW

VIDEOS

WATCH: GCTV17: Herbicide partnership.



6.5 Pre-emergent herbicides

Pre-emergent herbicides control weeds between radicle (embryonic root) 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.
- Positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [32]

To maximise the efficacy of pre-emergent herbicides while minimising crop damage, it is important to know:

- 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
- the herbicide's ability to be bound by the soil.

31 Agriculture Victoria. Monitoring Tools, http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

32 DAFWA (2016) Herbicides, 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. Typically, pre-emergent herbicides have more variables that can influence efficacy. Post-emergent herbicides are applied when weeds are present and the main considerations usually relate to application coverage, weed size and environmental conditions that impact on performance. Pre-emergent herbicides are applied before the weeds germinate; the various pre-emergent herbicides behave differently in the soil and may behave differently in different soil types. It is therefore essential to know the behaviour of the herbicide, the soil type and the farming system in order to use pre-emergent herbicides most effectively.

Pre-emergent herbicides must be absorbed by the germinating seedling from the soil. To do so, these herbicides must have some solubility in water and be positioned in the soil to be absorbed by the roots or emerging shoot. The dinitroaniline herbicides (such as trifluralin) are an exception because they are absorbed by the seedlings as a gas; however, 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.

6.5.2 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
- the rate of breakdown of the herbicide in the soil.

Characteristics of some common pre-emergent herbicides are given in 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 a herbicide moves too far through the soil profile, it risks 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.

Table 3: *Water solubility, binding characteristics to soil organic matter (Koc) and degradation half-life for some common pre-emergent herbicides.*

Herbicide	Water solubility (at 20°C and neutral pH)		Koc (in typical neutral soils)		Degradation half-life (days)
	(mg/L)	Rating	(mL/g)	Rating	
Trifluralin	0.22	Very low	15,800	Very high	181
Pendimethalin	0.33	Very low	17,800	Very high	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	3,000	High	82
Prosulfocarb	13	Low	2,000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	75.5
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23
Chlorsulfuron	12,500	Very high	40	Low	160

Some rules of thumb for maximising pre-emergent herbicide efficacy while minimising crop damage 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 (PSPE) 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 present 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 can inhibit pre-emergent herbicide action because they prevent the herbicide from contacting the seed. More water-soluble herbicides cope better with crop residue, but it is best to manage crop residue so that at least 50% of the soil surface is exposed at the time of application.
5. If the soil is dry on the surface but moist underneath, there may be sufficient moisture to germinate the weed seeds but not enough to activate the herbicide. Poor weed control is likely under these circumstances. The more water-soluble herbicides are less adversely affected under these conditions.
6. Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular, care needs to be taken with disc seeding equipment in choice of product and maintaining an adequate seeding depth. [33]

6.5.3 Top tips for using pre-emergent herbicides

- Only use pre-emergent herbicides as part of an IWM 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. Exclude sheep if possible.
- 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 machine and the limitations it may carry relative to a knife-point and press-wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the interrow while maintaining a seed furrow free from herbicide.
- Ensure that 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.
- Incorporate by sowing (IBS) rather than PSPE for crop safety.
- Understand herbicide chemistry. Choose the right herbicide for the paddock at the right rate. [34]

6.5.4 Post-sowing pre-emergent (PSPE) herbicide use

Post-sowing pre-emergent herbicide use is the application of pre-emergent herbicides to the seedbed after sowing (but before crop emergence). PSPE herbicides are primarily absorbed through the roots, but there may also be some foliar absorption (e.g. Terbyne®).

MORE INFORMATION

GRDC Update Paper: Understanding pre-emergent cereal herbicides

NSW DPI: Using pre-emergent herbicides in conservation farming systems

WeedSmart: Gearing up to use pre-emergent herbicides

GRDC Fact Sheet: Pre-emergent herbicides

GRDC Media Centre: How pre-emergent herbicides work

33 C Preston (2014) Understanding pre emergent cereal herbicides. GRDC Update Papers, March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Understanding-pre-emergent-cereal-herbicides

34 B Haskins. 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

When applied to soil, best control is achieved when the soil is flat and relatively free of clods and trash. Sufficient rainfall (2–30 mm) to wet the soil through the weed root-zone is necessary within 2–3 weeks of application. Assuming such conditions, best weed control is achieved from PSPE application because rainfall gives the best incorporation. Mechanical incorporation pre-sowing (IBS) is less uniform, and so weed control may be less effective; however, with pre-sowing application and sowing with minimal disturbance, incorporation will essentially be by rainfall after application.

MORE INFORMATION

NSW DPI Management Guide: Weed control in winter crops 2016 (pp. 44–45)

6.5.5 Incorporation by sowing (IBS)

The IBS method is when a herbicide is applied just before sowing (usually in conjunction with a knockdown herbicide such as glyphosate) and then soil-throw from the sowing operation incorporates the herbicide into the seedbed. IBS is the preferred method of applying pre-emergent herbicides in conservation farming systems, as crop safety is maximised, stubble remains standing to protect the seedbed, and soil disturbance is minimised.

The IBS method will often increase crop safety because the sowing operation removes a certain amount of herbicide away from the seed row. However, this can reduce weed control for the same reason, as the 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.

6.5.6 Control of annual ryegrass and crop safety with use of pre-emergent residual herbicides

Two trials (tyne-planted and disc-planted) were conducted in 2013 to evaluate the crop safety and efficacy of registered residual herbicides for the control of annual ryegrass in wheat. Most treatments were managed by the IBS approach, which specifies the use of narrow-point tynes on the planting equipment. PSPE was also evaluated.

Key findings

Planting method

- The use of a disc planter for 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 use only narrow-point tynes when using residual herbicides with IBS recommendations.

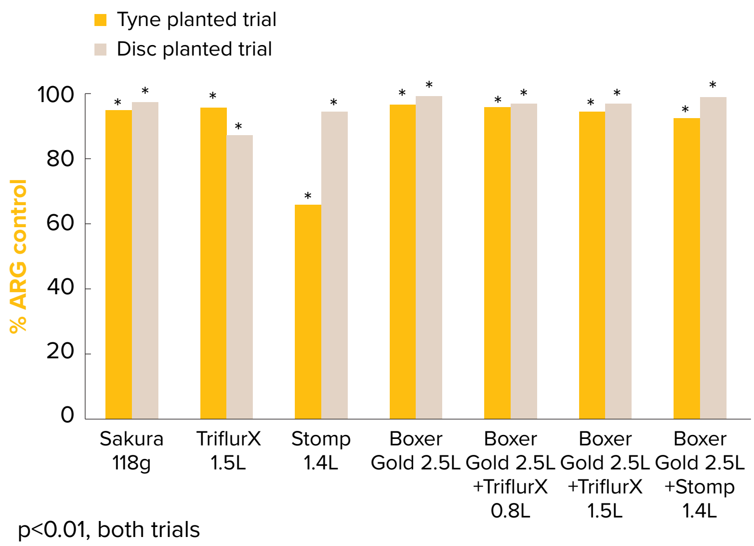


Figure 1: *Annual ryegrass (ARG) control based on counts on 22 September 2013, 94 days after planting, as a percentage of the untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa. *Significant (P < 0.05) weed control compared with untreated within same trial.*

Source: GRDC

Herbicide efficacy

- High levels of annual ryegrass control were achieved by most IBS treatments.
- The most consistent products 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 because of safety concerns for commercial crops arising from the use of residual herbicides at planting for control of annual ryegrass. The 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 might have affected crop safety.

This work reinforces some of the difficulties that 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, and rainfall quantity and timing. A more thorough understanding of the impacts from these (and perhaps other) factors is needed to get the best from these important weed-management tools. [35]

35 R Daniel, A Mitchell (2014) Pre-emergent herbicides; part of the solution but much still to learn. GRDC Update Papers, March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn

6.6 In-crop herbicides: knock-downs and residuals

In-crop herbicides control weeds that have emerged since crop or pasture establishment and they 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 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:

- Careful consideration is needed 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.
- The effectiveness of post-emergent herbicides is influenced by a range of plant and environmental factors. [36]

MORE INFORMATION

NSW DPI Management Guide: Weed control in winter crops 2016 (pp. 64–68)

6.6.1 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.
- 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. [37]

In-crop herbicides will normally require a different set of nozzles from those used in summer fallow spraying and application of pre-emergent herbicides.

In-crop post-emergent herbicides should be applied in the droplet spectrum from upper-end medium to lower-end coarse, depending on the particular herbicide being used. This must be combined with the relevant application volume to obtain enough droplets per cm^2 on the target for good coverage. Nozzles must also be matched the to the spray rig, pump and controller, and desired travel speed.

36 DAFWA (2016) Herbicides. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2

37 GRDC (2014) In-crop herbicide use. GRDC Fact Sheets, August 2014, https://grdc.com.au/Resources/Factsheets/2014/08/In-crop-herbicide-use

MORE INFORMATION

GRDC Fact Sheet: In-crop herbicide use

Operate within the recommended groundspeed 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.

6.6.2 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 (if unsure, send plants away for a Weed Resistance Quick-Test.
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or (for some chemicals) cloudy or sunny days. This is especially pertinent for grass-weed chemicals with frosts.
- 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. [38]

6.7 Conditions for spraying

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 several 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.

All grass herbicide labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions (Photo 12). 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 N
- 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.

Ensure that grass weeds have fully recovered before applying grass herbicides.

38 WeedSmart. Post-emergents, http://www.weedsmart.org.au/post-emergents/

Photo 12: *Boom spray on crop.*

Source: DAFWA

6.7.1 Minimising spray drift

Before spraying

- Always check for susceptible crops in the area, e.g. broadleaf crops such as grape vines, cotton, vegetables and pulses if you are using a broadleaf herbicide.
- Check sensitive areas such as houses, schools, waterways and riverbanks.
- Notify neighbours of your spraying intentions.

Under the Records Regulation of the Pesticides Act 1999, when spraying you must record the weather and relevant spray details.

During spraying

- Always monitor weather conditions carefully and understand their effect on 'drift hazard'.
- Do not spray if conditions are not suitable, and stop spraying if conditions change and become unsuitable.
- Record weather conditions (especially temperature and relative humidity), wind speed and direction, herbicide and water rates, and operating details for each paddock.
- Supervise all spraying, even when a contractor is employed. Provide a map marking the areas to be sprayed, buffers to be observed and sensitive crops and areas.
- Spray when temperatures are less than 28°C.
- Maintain a downwind buffer. This may be in-crop, e.g. keeping a boom's width from the downwind edge of the field.
- Minimise spray release height.
- Use the largest droplets that will give adequate spray coverage.
- Always use the least volatile formulation of herbicide available.
- If there are sensitive crops in the area, use the herbicide that will cause no off-target impacts.

Delta T, the relationship between temperature and relative humidity, gives a score for deciding the best times to apply sprays on crops. It is calculated by subtracting the wet bulb temperature from the dry bulb temperature. The ideal is between two and eight. (See: http://www.spraywisedecisions.com.au/Home/Faq.)

6.7.2 Types of drift

Sprayed herbicides can drift as droplets, vapours or particles:

- *Droplet drift* is the easiest to control because under good spraying conditions, droplets are carried down by air turbulence and gravity, to collect on plant or soil surfaces. Droplet drift is the most common cause of off-target damage caused by herbicide application. For example, spraying of fallows with glyphosate under the wrong conditions often leads to severe damage to establishing crops.
- *Particle drift* occurs when water and other herbicide carriers evaporate quickly from the droplet, leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. This form of drift has damaged susceptible crops up to 30 km from the source.
- *Vapour drift* is confined to volatile herbicides such as 2,4-D ester. Vapours may arise directly from the spray or evaporation of herbicide from sprayed surfaces. Use of 2,4-D ester in summer can lead to vapour-drift damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans and grapes. This may occur hours after the herbicide has been applied.

In 2006, APVMA, the federal regulators of pesticide use, restricted the use of highly volatile 2,4-D ester. The changes are now seen with the substitution of lower volatility forms of 2,4-D and MCPA. Products with lower risk ester formulations are commonly labelled with 'LVE' (i.e. low volatile ester). Although these formulations have a much lower tendency to volatilise, caution remains because they are still prone to droplet drift.

Vapours and minute particles float in the airstream and are poorly collected on catching surfaces. They may be carried for many kilometres in thermal updraughts before being deposited.

Sensitive crops may be up to 10,000 times more sensitive than the crop being sprayed. Even small quantities of drifting herbicide can cause severe damage to highly sensitive plants.

6.7.3 Factors affecting the risk of spray drift

Any herbicide can drift. The drift hazard, or off-target potential, of a herbicide in a particular situation depends on the following factors:

- Volatility of the formulation applied. Volatility refers to the likelihood that the herbicide will evaporate and become a gas. Esters volatilise (evaporate) whereas amines do not.
- Proximity of crops susceptible to the particular herbicide being applied, and their growth stage. For example, cotton is most sensitive to Group I herbicides in the seedling stage.
- Method of application and equipment used. Aerial application releases spray at three metres above the target and uses relatively low application volumes, whereas ground-rigs have lower release heights and generally higher application volumes, and a range of nozzle types. Misters produce large numbers of very fine droplets that use wind to carry them to their target.
- Size of the area treated. The greater the area treated the longer it takes to apply the herbicide. If local meteorological conditions change, particularly in the case of 2,4-D ester, then more herbicide is able to volatilise.
- Amount of active ingredient (herbicide) applied. The more herbicide applied per hectare the greater the amount available to drift or volatilise.
- Efficiency of droplet capture. Bare soil cannot catch drifting droplets, unlike crops, erect pasture species and standing stubbles.

- Weather conditions during and shortly after application. Changing weather conditions can increase the risk of spray drift.

Volatility

Table 4 is a guide to the volatility of more common herbicide active ingredients that are marketed with more than one formulation.

Table 4: *Relative volatility of herbicides.*

Form of active	Full name	Product example
Non-volatile		
Amine salts		
MCPA dma	Dimethyl amine salt	MCPA 500
2,4-D dma	Dimethyl amine salt	2,4-D Amine 500
2,4-D dea	Diethanolamine salt	2,4-D Amine 500 Low Odour®
2,4-D ipa	Isopropylamine salt	Surpass® 300
2,4-D tipa	Triisopropanolamine	Tordon® 75-D
2,4-DB dma	Dimethyl amine salt	Buttress®
Dicamba dma	dimethyl amine salt	Banvel® 200
Triclopyr tea	Triethylamine salt	Tordon® Timber Control
Picloram tipa	Triisopropanolamine	Tordon® 75-D
Clopyralid dma	Dimethylamine	Lontrel® Advanced
Clopyralid tipa	Triisopropanolamine	Archer®
Aminopyralid K salt	potassium salt	Stinger®
Aminopyralid tipa	Triisopropanolamine	Hotshot®
Other salts		
MCPA Na salt	Sodium salt	MCPA 250
MCPA Na/K salt	Sodium and potassium salt	MCPA 250
2,4-DB Na/K salt	Sodium and potassium salt	Buticide®
dicamba Na salt	Sodium salt	Cadence®
Some volatility		
Ester		
MCPA ehe	Ethylhexyl ester	LVE MCPA
MCPA ioe	Isooctyl ester	LVE MCPA
Triclopyr butoxyl	Butoxyethyl ester	Garlon® 600
Picloram ioe	Isooctyl ester	Access®
2,4-D ehe	Ethylhexyl ester	2,4-D LVE 680
Fluroxypyr M ester	Meptyl ester	Starane® Advanced

Source: Mark Scott, former Agricultural Chemicals Officer, NSW Agriculture

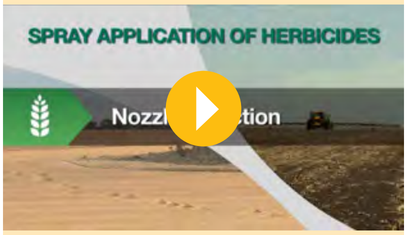
6.7.4 Equipment and settings for minimising drift

Selection of equipment to reduce the number of small droplets produced is a significant component of minimising spray drift. However, this may in turn affect coverage of the target, and hence the possible effectiveness of the pesticide application. This aspect of spraying needs to be carefully considered when planning to spray.

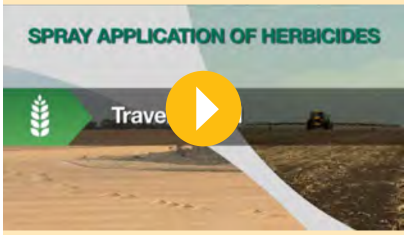
As the number of smaller droplets decreases, so does the coverage of the spray. A good example of this is the use of air-induction nozzles that produce large droplets

VIDEOS

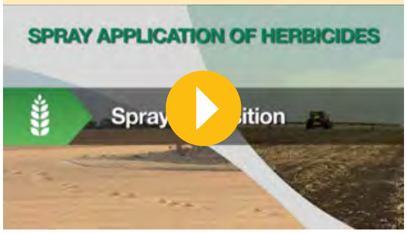
WATCH: Nozzle Selection.



WATCH: Travel Speed.



WATCH: Spray deposition.



that splatter. These nozzles produce a droplet pattern and number unsuitable for targets such as seedling grasses that present a small vertical target.

In 2010, APVMA announced new measures to minimise the number of spray-drift incidents (Table 5). The changes are restrictions on the droplet-size spectrum that an applicator can use, wind speed suitable for spraying and the downwind buffer zone between spraying and a sensitive target. These changes should be evident on current herbicide labels. Hand-held spraying application is exempt from these regulations.

Table 5: *Nozzle selection guide for ground application.*
Volume median diameter: 50% of droplets are less than the stated size and 50% greater. For flat-fan nozzle size, refer to manufacturers' selection charts because droplet size range will vary with recommended pressure; always use the lowest pressure stated to minimise number of small droplets.

Distance downwind to susceptible crop	**<1 km**	**1 to >30 km**
Risk	High	Medium
Preferred droplet size (British Crop Protection Council) (to minimise risk)	Coarse to very coarse	Medium to coarse
Volume median diameter (µm)	310	210
Pressure (bars)	2.5	2.5
Flat-fan nozzle size #	11,008	11,004
Recommended nozzles (examples only)	*Raindrop:* Whirljet® *Air induction:* Yamaho®, Turbodrop®, Hardi Injet®, Al Teejet®, Lurmark Drift-beta®	*Drift reduction:* DG TeeJet®, Turbo TeeJet®, Hardi® ISO LD 110, Lurmark® Lo-Drift
CAUTION	Can lead to poor coverage and control of grass weeds. Require higher spray volumes	Suitable for grass control at recommended pressures. Some fine droplets

Adapted from P. Hughes, QDPI
Source: NSW DPI

Spray release height

- Operate the boom at the minimum practical height. Drift hazard doubles as nozzle height doubles. If possible, angle nozzles forward 30° to allow lower boom height with double overlap. Lower heights, however, can lead to more striping as the boom sways and dips below the optimum height.
- 110° nozzles produce a higher percentage of fine droplets than 80° nozzles, but they allow a lower boom height while maintaining the required double-overlap.
- Operate within the pressure range recommended by the nozzle manufacturer. Production of driftable, fine droplets increases as the operating pressure is increased.

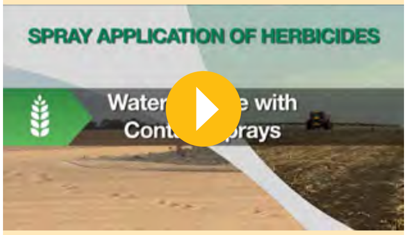
Size of area treated

When large areas are treated, greater amounts of active herbicide are applied and the risk of off-target effects increases due to the length of time taken to apply the herbicide. Conditions such as temperature, humidity and wind direction may change during spraying.

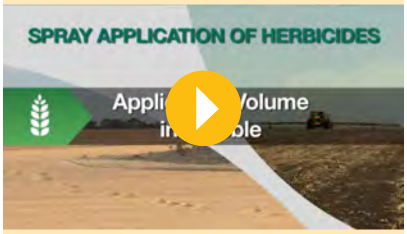
Application of volatile formulations to large areas increases the chances of vapour drift damage to susceptible crops and pastures.

VIDEOS

WATCH: Water volume with contact sprays.



WATCH: Application volume in stubble.



WATCH: Advances in weed management – Webinar 2 – Spray application in summer fallows.

Capture surface

Targets vary in their ability to collect or capture spray droplets. Well grown, leafy crops are efficient collectors of droplets. Turbulent airflow normally carries spray droplets down into the crop within a very short distance.

Fallow paddocks or seedling crops have poor catching surfaces. Drift hazard is far greater when applying herbicide in these situations or adjacent to these poor capture surfaces.

The type of catching surface between the sprayed area and susceptible crops should always be considered in conjunction with the characteristics of the target area when assessing drift hazard.

6.7.5 Weather conditions to avoid

Turbulence

Updrafts during the heat of the day cause rapidly shifting wind directions. Spraying should be avoided during this time.

High temperatures

Avoid spraying when temperatures exceed 28°C.

Humidity

Avoid spraying under conditions of low relative humidity, i.e. when the difference between wet and dry bulbs (i.e. Delta T) exceeds 10.

High humidity extends droplet life and can greatly increase the drift hazard under inversion conditions. This results from the increased life of droplets to less than 100 microns.

Wind

Avoid spraying under still conditions. Ideal safe wind speeds are 3–10 km per hour (a light breeze, i.e. when leaves and twigs are in constant motion).

Wind speeds of 11–14 km per hour (a moderate breeze, i.e. when small branches move, dust is raised and loose paper is moving) are suitable for spraying if using low-drift nozzles or higher volume application, say 80–120 L/ha.

Inversions

The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity. An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, usually <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.

Do not spray under inversion conditions.

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. [39]

39 A Storrie (2015) Reducing herbicide spray drift. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift

6.8 Herbicide tolerance ratings

Within many broadacre crop species, cultivars have been found to vary in sensitivity to commonly used herbicides and tank mixes, thereby resulting in potential grain yield loss and reduced farm profit. With funding from GRDC and state government agencies across Australia, cultivar × herbicide tolerance trials are conducted annually.

The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species including wheat, barley, triticale, oats, lupins, field peas, lentils, chickpeas and faba beans. The intention is to provide data from at least two years of testing at the time of wide-scale commercial propagation of a new cultivar. [40]

The good news is that over 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. These results were measured 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 now been combined under a national program. [41]

In greenhouse trials in the US, cereal rye showed tolerance similar to oats for a range of residual herbicides (based on injury rating). Cereal rye had a higher potential for injury from the Group K herbicide S-metolachlor. [42]

6.9 Potential herbicide damage effect

6.9.1 Avoiding crop damage from residual herbicides

The herbicide label is the primary source of information on residual activity and cropping restrictions following herbicide application and it should be read thoroughly. The following information provides an explanation of how herbicides break down and extra information on some specific herbicides used in broadacre cropping.

What are the issues?

Some herbicides can remain active in the soil for weeks, months or years. This can be advantageous, 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 (Glean®) is used in wheat and barley, but it can remain active in the soil for several years and damage legumes and oilseeds. A problem for growers lies in identifying herbicide residues before they cause a problem.

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, and if testing is possible, it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease. [43]

An option for assessing the potential risk of herbicide residues is to conduct a bioassay involving hand-planting of small test areas of crop into the field in question.

40 NVT. Herbicide tolerance. GRDC, http://www.nvtonline.com.au/herbicide-tolerance/

41 E Leonard (2012) Weed kill without crop damage. GRDC Ground Cover Supplements, November 2012, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS101/Weed-kill-without-crop-damage

42 B Hartzler, M Anderson (2015) Effect of residual herbicides on cover crop establishment. Iowa State University Extension and Outreach, http://www.weeds.iastate.edu/mgmt/2015/CCherbicides.pdf

43 DEPI (2013) Avoiding crop damage from residual herbicides. Department of Environment and Primary Industries Victoria, http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

Which herbicides are residual?

The herbicides listed in Table 6 all have some residual activity or planting restrictions. For example, Glean®, registered in cereal rye, wheat, triticale, and oats, has activity through root and foliar uptake. Plant-back recommendations on alkaline soils are three months for cereal rye. [44]

Table 6: *Active constituents (and examples of commercially available herbicide products) that have some residual activity, by herbicide group*
List may not include all current herbicides.

Herbicide MoA group and class	Active constituent
Group B: sulfonylureas	Chlorsulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)
Group B: imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)
Group B: triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)
Group C: triazines	Atrazine, simazine
Group C: triazinones	Metribuzin (Sencor®)
Group C: ureas	Diuron
Group D: dinitroanilines	Pendimethalin (Stomp®), trifluralin
Group H: pyrazoles	Pyrasulfotole (Precept®)
Group H: isoxazoles	Isoxaflutole (Balance®)
Group I: phenoxy carboxylic acids	2,4-Ds
Group I: benzoic acids	Dicamba
Group I: pyridine carboxylic acids	Clopyralid (Lontrel®)
Group K: chloroacetamides	Metolachlor
Group K: isoxazolines	Pyroxasulfone (Sakura®)

How to avoid damage from residual herbicides

Select an appropriate herbicide for the weed population. Consider the re-cropping limitations with respect to future rotation options.

Users of chemicals are required by law to keep good records, including weather conditions, but particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock) (Photo 13). In the case of unexpected damage, good records can be invaluable.

If residues could be present, choose the least susceptible crops (refer to product labels). Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues. [45]

44 L Lenaghan. Residual herbicides Group B and C carry-over. CropPro, http://www.croppro.com.au/resources/BCGGroupBResidual_herbicides(2)[1].pdf

45 DEPI (2013) Avoiding crop damage from residual herbicides. Department of Environment and Primary Industries Victoria, http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

MORE INFORMATION

NSW DPI: Herbicide residues in soil and water

Photo 13: *Trial plot showing crop damage with pre-emergent herbicides due to poor separation of herbicide and crop seed.*

Photo: Dr Christopher Preston. Source: GRDC

6.9.2 Plant-back intervals

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop.

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original, what remains can persist for long periods (e.g. sulfonylureas such as chlorsulfuron). This is shown in the Table 7 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 (Table 8).

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonylureas, triazines, etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [46]

46 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

Table 7: *Residual persistence of common pre-emergent herbicides in broadacre trials and from farm paddock situations.* [47]

Herbicide	Residual persistence and prolonged weed control
Logran® (triasulfuron)	High. Persists longer in high-pH soils. Weed control commonly drops off within 6 weeks
Glean® (chlorsulfuron)	High. Persists longer in high-pH soils. Weed control longer than Logran®
Diuron	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed long-lasting activity on grass weeds such as black/stink grass (*Eragrostis* spp.) and to a lesser extent broadleaf weeds such as fleabane
Atrazine	High. Has had observed long-lasting (>3 months) activity on broadleaf weeds such as fleabane
Simazine	Medium/high. One year residual in high-pH soils. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane
Terbyne® (terbuthylazine)	High. Has had observed long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sowthistle
Triflur® X (trifluralin)	High. 6–8 months residual. Higher rates longer. Has had observed long-lasting activity on grass weeds such as black/stink grass
Stomp® (pendimethalin)	Medium. 3–4 months residual
Avadex® Xtra (triallate)	Medium. 3–4 months residual
Balance® (isoxaflutole)	High. Reactivates after each rainfall event. Has had observed long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sowthistle
Boxer Gold® (prosulfocarb)	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event
Sakura® (pyroxasulfone)	High. Typically quicker breakdown than trifluralin and Boxer Gold®; however, weed control persists longer than Boxer Gold®

47 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

Table 8: *Minimum re-cropping intervals and guidelines for some Group B herbicides.*

Class	Herbicide	pH(H_2O)	Minimum re-cropping interval (months after application), rainfall and other conditions
Sulfonylurea	Chlorsulfuron: e.g. Glean®, Seige®, Tackle®	<6.5	3 months
		6.6–7.5	3 months, minimum 700 mm
		7.6–8.5	18 months, minimum 700 mm
Sulfonylurea	Triasulfuron: e.g. Logran®, Nugrain®	7.6–8.5	12 months, >250 mm (grain), 300 mm (hay)
		>8.6	12 months, >250 mm (grain), 300 mm (hay)
Sulfonamide	Flumetsulam: e.g. Broadstrike®		0 months
Sulfonylurea	Metsulfuron: e.g. Ally®, Associate®	5.6–8.5	1.5 months
		>8.5	Tolerance of crops grown through to maturity should be determined (small-scale) in the previous season before sowing larger area
Sulfonylurea	Metsulfuron + thifensulfuron: e.g. Harmony® M	7.8–8.5, organic matter >1.7%	3 months
		>8.6 or organic matter <1.7%	Tolerance of crops grown through to maturity should be determined (small scale) in the previous season before sowing larger area
Sulfonylurea	Sulfosulfuron: eg Monza®	<6.5	0 months
		6.5–8.5	10 months

NOTE: always read labels to confirm

Source: Pulse Australia

Conditions required for breakdown

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

For up-to-date plant-back periods, see the NSW DPI publication: Weed control in winter crops.

MORE INFORMATION

Agriculture Victoria: Avoiding crop damage from residual herbicides

6.10 Herbicide resistance

6.10.1 Understanding herbicide resistance

Herbicide resistance facts

- Resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a wild type individual of the same species.
- Herbicide-resistant individuals are present at very low frequencies in weed populations before the herbicide is first applied.
- The frequency of naturally resistant individuals within a population will vary greatly within and between weed species.
- Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide MoA.
- As at June 2014, Australian weed populations had developed resistance to 13 MoAs (click here for up-to-date statistics).
- A weed population is defined as resistant when a herbicide at a label rate that once controlled the population is no longer effective (sometimes an arbitrary figure of 20% survival is used for defining resistance in testing).
- The proportion of herbicide-resistant individuals will rise (due to selection pressure) in situations where the same herbicide MoA is applied repeatedly and the survivors are not subsequently controlled.
- Herbicide resistance in weed populations is permanent as long as seed remains viable in the soil. Only weed density can be reduced, not the ratio of resistant to susceptible individuals. The exception is when the resistance gene(s) carry a fitness penalty so that resistant plants produce less seed than susceptible ones—but this is rare.

Key messages

Characteristics of resistance:

- Resistance remains for many years, until all resistant weed seeds are gone from the soil seed bank
- Resistance evolves more rapidly in paddocks with frequent use of the same herbicide group, especially if no other control options are used.

Action points:

- Assess your level of risk with the online glyphosate resistance toolkit.
- Aim for maximum effectiveness in control tactics, because resistance is unlikely to develop in paddocks with low weed numbers.
- Do not rely on the same MoA group.
- Monitor your weed control regularly.
- Stop the seedset of survivors. [48]

Herbicide resistance has become far more widespread, reducing the effectiveness of a wide range of herbicide MoAs (Photo 14). Rapid expansion of herbicide resistance and the lack of new MoAs require non-herbicide tactics to be a significant component of any farming system and weed-management strategy. Inclusion of non-herbicide tactics is critical to prolonging the effective life of remaining herbicides, as well as new products and MoAs that have not yet been released or indeed invented. Effective herbicides are key components of profitable cropping systems. Protecting their efficacy directly contributes to the future sustainability and profitability of cropping systems.

48 QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

Photo 14: *2,4-D resistant radish, Wongan Hills.*

Photo: A Storrie. Source: GRDC

MORE INFORMATION

GRDC: IWM Hub—Herbicide resistance.

How does resistance start?

Resistance starts in a paddock in several ways. Some rare mutations can occur naturally in weeds already in the paddock, with the frequency varying from 1 plant in 10,000 to 1 in a billion plants, depending on the weed and herbicide. A grower may also import weed seed with the herbicide-resistant gene in contaminated feed, seed or machinery.

Resistance may also be introduced by natural seed spread by wind and water or by pollen, which may blow short distances from a contaminated paddock.

6.10.2 General principles to avoid resistance

Herbicides have a limited life before resistance develops if they are used repeatedly and as the sole means of weed control—particularly in no-till and minimum-till systems.

Resistance can develop within six–eight years for Group A and four–six years for Group B herbicides, 10–15 years for Groups C and D, and after 15 years for Groups L and M herbicides. [49] Figure 2 illustrates how the use of herbicide can lead to a resistant population. This can be avoided by:

- keeping weed numbers low
- changing herbicide groups
- using tillage
- rotating crops and agronomic practices.

Further insight has been gained into the impact and efficacy of IWM strategy components through a computer-simulated model. [50]

49 QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

50 QDAF (2015) Effectiveness of herbicide resistance management strategies. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance/effectiveness-of-resistance-management-strategies

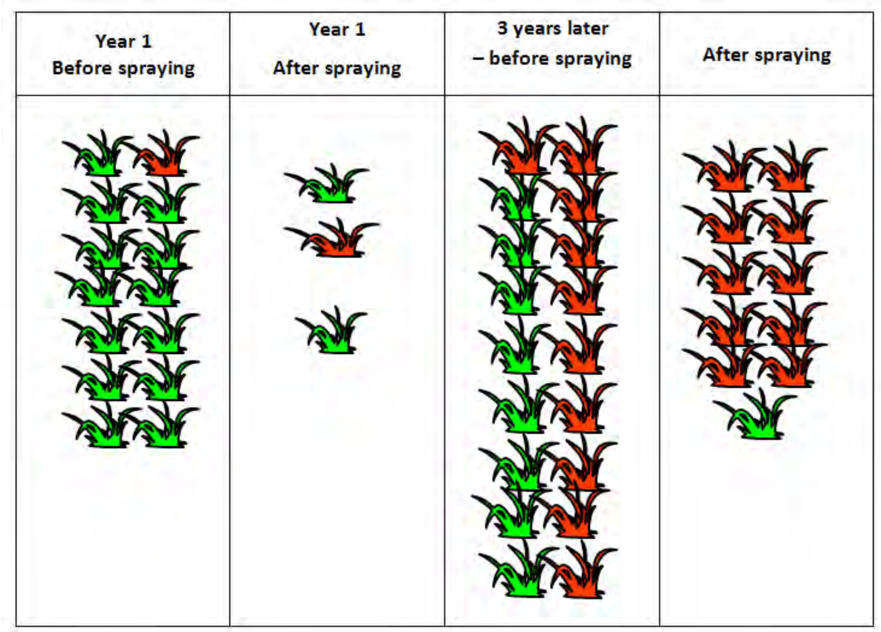


Figure 2: *How a weed population becomes resistant to herbicides; red indicates resistant plants.*

Source: GRDC

Strategies to prevent or minimise the risk of resistance developing are based on IWM principles as outlined below:

- Ensure that survivors do not set seed and replenish the soil seedbank.
- 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 MoA 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, because buried weed seed generally persists longer than seed 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.

Guidelines for reducing the risk of glyphosate resistance are outlined in Aim to include as many risk-decreasing factors as possible in your crop and weed management plans. [51]

51 QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

Table 9: *Risk factors 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: QDAF

Glyphosate-resistant weeds in Australia

Glyphosate resistance was first documented for annual ryegrass in 1996 in Victoria. Since then, glyphosate resistance has been confirmed in 11 other weed species. Resistance is known in eight grass species and four broadleaf species. Four are winter-growing weed species and eight summer-growing weed species. The latter have been selected mainly in chemical fallows and on roadsides (Photo 15).

Photo 15: *Winter fallow showing an early glyphosate-resistant sowthistle (Sonchus spp.) infestation.*

Photo: A Storrie. Source: GSWG

All of the glyphosate-resistant weed populations have occurred in situations where there has been intensive use of glyphosate, often over at least 15 years, few or no other effective herbicides used, and few other weed-control practices used. This suggests that the following are the main risk factors for the evolution of glyphosate resistance:

- intensive use of glyphosate—every year or multiple times a year for ≥15 years
- heavy reliance on glyphosate for weed control
- no other weed controls targeted to stop seedset.

MORE INFORMATION

AGSWG: Australian glyphosate resistance register

GRDC Fact Sheet: Strategic risk management factsheet

GRDC Fact Sheet: Farm business management factsheet

AHRI: RIM model

VIDEOS

WATCH: Act now: Plan your weed management program.

WATCH: Chaff carts 101.

WATCH: Capture weed seeds at harvest: Harrington seed destructor.

WATCH: Strategic narrow windrow burning.

Farming practices in chemical fallows are dependent on glyphosate for weed control. Therefore, it is highly likely that unconfirmed populations of glyphosate-resistant summer and winter weeds are present in this system.

Likewise, farming practices under the vines in vineyards across Australia are dependent on glyphosate for weed control, so unconfirmed populations of glyphosate-resistant annual ryegrass are very likely present in this system.

These unconfirmed glyphosate-resistant populations are not recorded on the register of glyphosate-resistant populations in Australia. [52]

The Queensland Department of Agriculture and Fisheries Glyphosate resistance toolkit enables growers and advisors to assess their level of risk for developing glyphosate-resistant weeds on their farm.

6.10.3 The 10-point plan to weed out herbicide resistance

1. Act now to stop weed seedset.

Creating a plan of action is an important first step of integrated weed management. A little bit of planning goes a long way!

- Destroy or capture weed seeds.
- Understand the biology of the weeds present.
- Remember that every successful WeedSmart practice can reduce the weed seedbank over time.
- Be strategic and committed—herbicide resistance management is not a one-year decision.
- Research and plan your WeedSmart strategy.
- You may have to sacrifice yield in the short term to manage resistance—be proactive.

2. Capture weed seeds at harvest.

Destroying or capturing weed seeds at harvest is the number one strategy for combating herbicide resistance and driving down the weed seed bank.

- Tow a chaff cart behind the header.
- Check out the 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.

52 C Preston. The Australian Glyphosate Sustainability Working Group, http://www.glyphosateresistance.org.au

VIDEOS

WATCH: The art of narrow windrow burning.

WATCH: Chaff funneling onto tramlines.

WATCH: Capture weed seeds at harvest: Bale Direct System.

WATCH: IWM: Weed seed destruction – Beer can height.

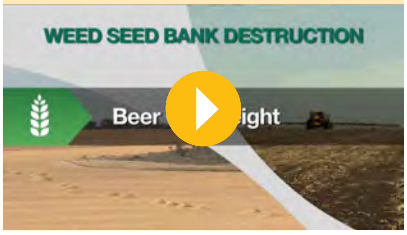


Photo 16: *Harrington Seed Destructor at work in the paddock.*

Source: GRDC

For information on harvest weed-seed control and its application, see Section 12: Harvest.

3. Rotate crops and herbicide MoA.

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 and pulses, swath canola, and delay sowing some crops (such as field peas).

Rotations that include both broadleaf crops (e.g. 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 not to repeatedly use herbicides from the same MoA group. Some crops have fewer 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 evolution of herbicide resistance.

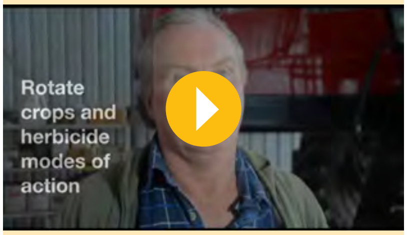
4. Test for resistance to establish a clear picture of paddock-by-paddock farm status.

- 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

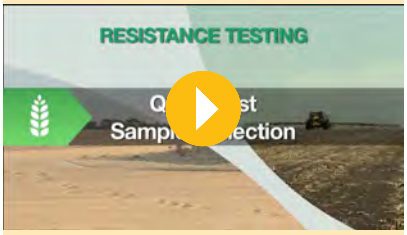
VIDEOS

WATCH: Crop rotation with Colin McAlpine.

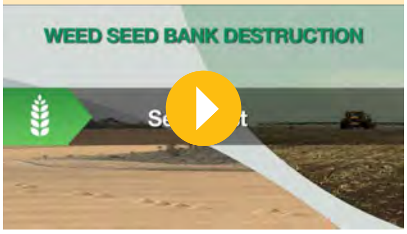


WATCH: Test for resistance to establish a clear picture of paddock-by-paddock farm status.

WATCH: IWM: Resistance Testing – Quick test sample collection.



WATCH: IWM: Seed test – What's involved.



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 in a game-changing situation such as the discovery of a rare resistance gene (e.g. glyphosate resistance), or to determine whether a patch of surviving weeds is any worse than the grower had 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.

- Always use the label rate
- Weeds resistance to multiple herbicides can result from below the rate sprays.

AHRI researcher Dr Roberto Busi found that annual ryegrass receiving below-the-rate Sakura® evolved resistance not only to Sakura® but also to Boxer Gold® and Avadex®. Imagine developing these multiple-resistant, monster weeds just because you cut the rate!

Aim for 100% control and monitor every spray event:

- Stop resistant weeds from returning to the farming system.
- Focus on management of survivors in fallows.
- Where herbicide failures occur, do not let the weeds seed. Consider cutting for hay or silage, fallowing or brown manuring the paddock.
- Patch-spray areas of resistant weeds only if appropriate.

6. Do not automatically reach for glyphosate.

Glyphosate has long been regarded as the world's most important herbicide, so it is natural to reach for it at the first sign of weeds. But what if it did not work anymore?

Resistance to this herbicide is very high in some areas and now it may fail for growers all across Australia. This is because too much reliance on one herbicide group gives the weeds opportunity to evolve resistance.

To preserve the status of glyphosate as the wonder weed-killer, we need to stop automatically reaching for it. Introduce paraquat products when dealing with smaller weeds, and for a long-term solution, farm with a very low seedbank:

- Use a diversified approach to weed management.
- Consider post-emergent herbicides where suitable.
- Consider strategic tillage.

VIDEOS

WATCH: Don't cut the rate.

WATCH: Don't automatically reach for glyphosate.

WATCH: Manage spray drift.

WATCH: Plant clean seed into clean paddocks with clean borders.

WATCH: Best results with double knock tactic.

7. Carefully manage spray events.

- Use best management practice in spray application.
- Consider selective weed sprayers such as WeedSeeker® or WEEDit®.

It is 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 it 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 target the application precisely. Also, many herbicide labels specify the droplet spectrum to be used when applying the herbicide (so take the time to read the label beforehand).

Generally, medium–coarse droplet size combined with higher application volumes provides better coverage of the target. Using a pre-orifice nozzle slows droplet speed, making them 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.

8. Plant clean seed into clean paddocks with clean borders.

- It is easier to control weeds before the crop is planted.
- Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
- A recent Australian Herbicide Resistance Initiative (AHRI) survey showed that 73% of grower-saved crop seed was contaminated with weed seed.
- The density, diversity and fecundity of weeds are generally greatest along paddock borders and areas such as roadsides, channel banks and fence lines.

Keep it clean! With herbicide resistance on the rise, planting clean seed into clean paddocks with clean borders is 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 Harrington Seed Destructor 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 is important to control these initial populations by keeping clean borders.

9. Use the double-knock technique.

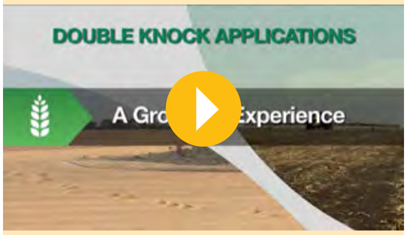
To use the double-knock technique, combine two weed-control tactics with different MoA on a single flush of weeds. These two knocks happen in sequential strategies; the second application designed to control any survivors from the first.

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 that the paraquat rate is high.

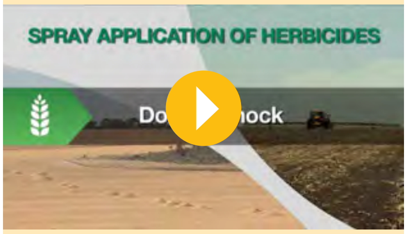
The best time to initiate a glyphosate–paraquat double-knock is after rainfall. New weeds will quickly begin to germinate and they should be tackled at this small stage.

VIDEOS

WATCH: Double knock application – a Grower's Experience.



WATCH: Spray application of herbicides – Double Knock.



WATCH: Double knock applications - target weed species & application strategy

WATCH: Learn to think outside the drum.

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. [53] [54]

If you think you have resistant weeds

When resistance is first suspected, growers should contact their local agronomist.

The following steps are then recommended:

1. Consider the possibility of other common causes of herbicide failure by asking:
   a. Was the herbicide applied in conditions and at a rate that should kill the target weed?
   b. Did the suspect plants miss herbicide contact or emerge after the herbicide application?
   c. Does the pattern of surviving plants suggest a spray miss or other application problem?
2. Has the same herbicide or herbicides with the same MoA been used in the same field or in the general area for several years?
3. Has the uncontrolled species been successfully controlled in the past by the herbicide in question or by the current treatment?
4. Has a decline in the control been noticed in recent years?
5. Is the level of weed control generally good on the other susceptible species?

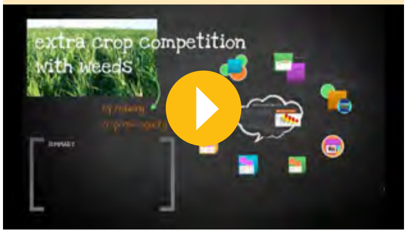
53 AHRI. Harvest weed seed control. GRDC/Australian Herbicide resistance Initiative, http://ahri.uwa.edu.au/~ahriuwae/wp-content/uploads/2014/10/1100-AHRI-Harvest-Weed-Seed-Control-Booklet-2013-version.pdf

54 WeedSmart 10 point plan. WeedSmart, http://weedsmart.org.au/10-point-plan/

VIDEOS

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)

If resistance is still suspected:

1. Contact a testing service (see below).
2. Ensure that 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. [55]

Testing services

For testing of suspected resistant samples, contact:

- Charles Sturt University Herbicide Resistance Testing
  School of Agricultural and Wine Sciences Charles Sturt University
  Locked Bag 588
  Wagga Wagga, NSW 2678
  02 6933 4001
  https://www.csu.edu.au/weedresearchgroup/herbicide-resistance
  CSU plant testing application form
- Plant Science Consulting P/L
  22 Linley Avenue, Prospect
  SA 5082, Australia
  info@plantscienceconsulting.com.au
  Phone: 0400 66 44 60

6.11 Monitoring weeds

Monitoring of weed populations before and after any spraying is an important part of management:

- Keep accurate records.
- Monitor weed populations and record results of herbicides used.
- If herbicide resistance is suspected, prevent weed seedset.
- If a herbicide does not work, find out why.
- Check that weed survival is not due to spraying error.
- Conduct your own paddock tests to confirm herbicide failure and determine which herbicides remain effective.
- Obtain a herbicide-resistance test on seed from suspected plants, testing for resistance to other herbicide MoA groups.
- Do not introduce or spread resistant weeds in contaminated grain or hay.

Regular monitoring is required to assess the effectiveness of weed management and the expected situation following weed removal or suppression. Without monitoring, we cannot assess the effectiveness of a management program or determine how it might be modified for improved results. Effective weed management begins with monitoring weeds to assess current or potential threats to crop production, and to determine best methods and timing for control measures.

Regular monitoring and recording details of each paddock allows the grower to:

- spot critical stages of crop and weed development for timely cultivation or other intervention;
- identify the weed flora (species composition), which helps to determine best short- and long-term management strategies; and
- detect new invasive or aggressive weed species while the infestation is still localised and able to be eradicated.

Watch for critical aspects of the weed–crop interaction, such as:

- weed-seed germination and seedling emergence
- weed growth sufficient to affect crops if left unchecked

55 QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

- weed density, height, and cover relative to crop height, cover, and stage of growth
- weed effects on crops, including harbouring pests, pathogens or beneficial organisms; or modifying microclimate, air circulation or soil conditions; as well as direct competition for light, nutrients, and moisture
- flowering, seedset, or vegetative reproduction in weeds
- efficacy of cultivations and other weed-management practices.

Information gathered through regular and timely field monitoring helps growers to select the best tools and timing for weed-control tactics. Missing vital cues in weed and crop development can lead to costly efforts to rescue a crop, efforts that may not be fully effective. Good paddock scouting can help the grower to obtain the most effective weed control for the least fuel use, labour cost, chemical application, crop damage and soil disturbance. [56]

6.11.1 Tips for monitoring

To scout weeds, walk slowly through the paddock, examining any vegetation that was not planted. In larger paddocks, walk back and forth in a zigzag pattern to view all parts of the paddock, noting areas of particularly high or low weed infestation. Identify weeds with the help of a good weed guide or identification key for your region, and note the weed species that are most prominent or abundant. Observe how each major weed is distributed through the paddock. Are the weeds randomly scattered, clumped or concentrated in one part of the paddock?

Keep records in a field notebook. Prepare a page for each paddock or crop sown, and take simple notes of weed observations each time the paddock is monitored. Over time, your notes become a timeline of changes in the weed flora over the seasons and in response to crop rotations, cover crops, cultivations and other weed control practices. Many growers already maintain separate records for each paddock; weed observations (species, numbers, distribution, size) can be included with these.

56 M Schonbeck (2011) Weed monitoring. Cooperative Extension System, http://articles.extension.org/pages/32636/weed-monitoring

Insect control

Key messages

- Cereal rye can attract armyworms. [1]
- An abundance of top growth that is poorly incorporated may cause poor seed-to-soil contact in the subsequent crop and may attract armyworms or cutworms. [2]
- Cereal rye can attract significant numbers of beneficial insects such as lady beetles. [3]
- 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).

Where chemical control is warranted, farmers are increasingly being strategic in their management and avoiding broad-spectrum insecticides where possible. Thresholds and potential economic damage are carefully considered.

Agronomist's view

7.1 Potential insect pests

Stay informed about invertebrate pest threats throughout the winter growing season by subscribing to SARDI's PestFacts South Australia and cesar's PestFacts south-eastern.

Subscribers to PestFacts also benefit from special access to cesar's extensive Insect Gallery, which can be used to improve skills in identifying pest and beneficial insects.

1 Penn State University. Cover crops for conservation tillage systems, http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/cover-crops-for-conservation-tillage-systems

2 Manure $ense (2009) Cereal Rye: Manure and livestock's new best friend, http://mccc.msu.edu/wp-content/uploads/2016/09/MI_2009_CerealRyeManure.pdf

3 A Clark (Ed.) 2007 Managing cover crops profitably. 3rd ed. SARE Outreach Handbook Series Book 9. National Agricultural Laboratory, Beltsville, MD, http://articles.extension.org/pages/18571/cereal-rye-for-cover-cropping-in-organic-farming

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
Wireworms	Damaging	Present		
Cutworm	Damaging			
Black headed cockchafer	Damaging	Present		
Earth mites	Damaging	Present		
Slugs, snails*	Damaging			
Brown wheat mite		Damaging		
Aphids	Present	Damaging	Present	Present
Armyworm		Present	Present	Damaging
Helicoverpa armigera				Damaging

* Snails are also a grain contaminant at harvest

Source: IPM Guidelines

Use Table 3 to identify damage caused by key pests, and to assess risk and determine control measures for establishment pests.

Table 3: *Establishment pests affecting cereal crops in the southern cropping region.*

	Pre-season	Pre-sowing	Emergence	Crop-establishment
Earth Mites and Lucerne Flea	Assess Risk. High risk when: • History of high mite pressure. • Pasture rotating into crop. • Susceptible crop being planted (e.g. canola, pasture, Lucerne). • Seasonal forecast is for dry or cool, wet conditions that slow crop growth. If risk is high: • Ensure accurate identification. • Use Timerite (redlegged earth mites only). • Heavily graze pastures in early-mid spring.	If high risk: • Use an insecticide seed dressing on susceptible crops. • Plan to monitor more frequently until crop establishment. • Use higher sowing rate to compensate for seedling loss. • Consider scheduling a post-emergent insecticide treatment. If low risk: • Avoid insecticide seed dressings (esp. cereal and pulse crops) and plan to monitor until crop establishment.	Monitor susceptible crops through to establishment using direct visual searches. Be aware of edge effects; mites move in from weeds around paddock edges. If spraying: • Ensure accurate identification of species before deciding on chemical. • Consider border sprays (mites) and 'spot' sprays (Lucerne flea). • Spray prior to winter egg production to suppress populations and reduce risk in the following season.	As the crop grows, it becomes less susceptible unless growth is slowed by dry or cool, wet conditions.

	Pre-season	Pre-sowing	Emergence	Crop-establishment
Slugs	Assess risk. High risk when: • High Stubble load. • Annual average .rainfall >450 mm • History of Slug infestations. • Canola being planted. • Summer rainfall. • Heavy clay soils.	If high risk: • Burn stubbles. • Cultivate worst areas. • Remove weeds in paddocks/along fence-lines, at least 8 weeks prior to sowing. • Deploy shelter traps prior to sowing. • Sow early to get crop established prior to cold conditions. • Use soil compaction at sowing (e.g. press wheels). • Bait at/after sowing prior to emergence.	Assess risk. High risk under cold conditions and slow plant growth. Use shelter traps or directly search at night when slugs are active to confirm slugs as the cause of seedling loss. If slug pressure is high, successive baiting may be necessary. Monitoring will guide bait use.	As the crop grows, it becomes less susceptible unless growth is slowed by cool conditions. Re-sowing may be required if plant stands are unsatisfactory.
False wireworm and true wireworm	Assess risk. High risk when: • History of wireworm pressure. • Soils high in organic matter. • High stubble and summer/ autumn litter cover.	Conduct direct visual search for adult beetles over summer and autumn. Directly search (in soil) for beetle larvae 2 weeks prior to sowing. If high risk: • Re-assess crop choice or timing of sowing. • Consider an insecticide seed dressing (particularly fipronil) or in-furrow treatment. • Use soil compaction at sowing (e.g. Press wheels). • Consider higher sowing rate to compensate for seedling loss.	Limited options for control once crop is sown. Consider re-sowing severely affected areas of crop.	Damage to established crops is rare.
Scarabs	Assess risk. High risk when: • Sowing crop into pasture, esp. those with a high clover content. • Previous history of scarab damage to crop in that field. • Wetter than average seasons. • Minimum/no tillage. Under high pressure: • Spray African black beetle adults in spring. • Avoid overgrazing pastures.	Dig soil within paddock to determine incidence of scarab larvae. If high risk: • Cultivate land. • Avoid sowing grass pastures. • Use soil compaction at sowing (e.g. press wheels) • Consider higher sowing rate to compensate for seedling loss.	Assess risk. High risk when dry conditions slow plant growth. Limited options for control once crop is sown. Larvae of most species do not emerge from the soil. For black headed pasture cockchafer, spray around heavy dews or light rainfall which will trigger larvae activity.	Re-sowing may be an option, but as some species have a 2-year life cycle, larvae can persist through winter into spring. ID will guide this decision.

	Pre-season	Pre-sowing	Emergence	Crop-establishment
Others (e.g. earwigs, slaters, millipedes, weevils)	Assess risk. High risk when: • History of high pest pressure. • Minimum/no tillage. • High stubble load. • Heavier soils. • Monitor in spring using shelter traps, direct searches and/or pitfall traps.	If high risk: • Burn stubbles. • Cultivate worst areas. • Use cracked wheat baits. • Avoid sowing canola.	Monitor susceptible crops through to establishment. Directly search at night to confirm pest species at the cause of seedling loss (note: large numbers of these pests can be found in paddocks without causing crop damage).	Damage to established crops is rare.

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.

Insecticide resistance

- RLEM has been found to have high levels of resistance to synthetic pyrethroidssuch as bifenthrin and alpha-cypermethrin.
- *Helicoverpa armigera* has historically had high resistance to pyrethroids and the inclusion of NPV is effective where mixed populations of armyworm and helicoverpa occur in maturing winter cereals. [4]

VIDEOS

WATCH: Integrated Pest Management.

4 IPM Guidelines. Winter cereals. GRDC and DAFF, http://ipmguidelinesforgrains.com.au/crops/winter-cereals/

7.2.1 Insect sampling methods

Monitoring for insects is an essential part of successful integrated pest management programs. Correct identification of immature and adult stages of both pests and beneficials, and accurate assessment of their presence in the field at various crop stages, will ensure appropriate and timely management decisions. Good monitoring procedure involves not just a knowledge of and the ability to identify the insects present, but also good sampling and recording techniques and a healthy dose of common sense.

Factors that contribute to quality monitoring

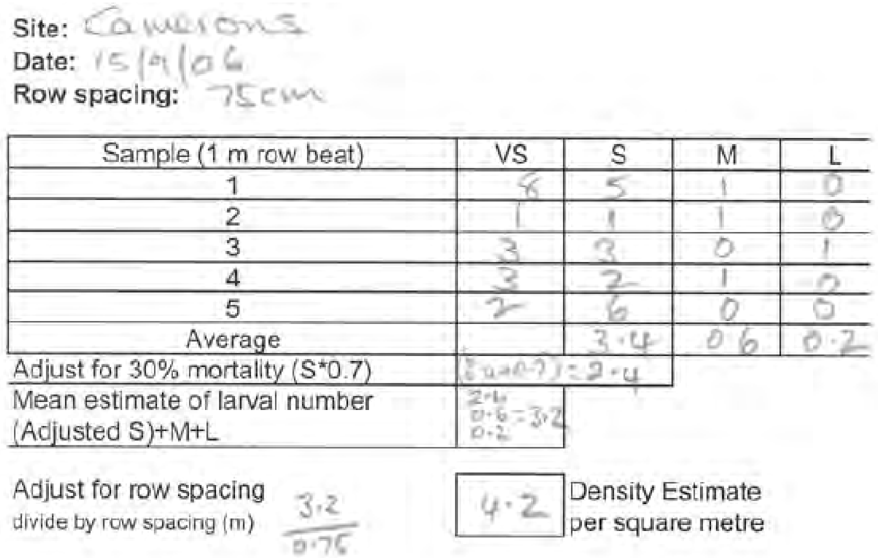
- **Knowledge of likely pests/beneficials and their life cycles** is essential when planning your monitorng program. As well as visual identification, you need to know where on the plant to look and the best time of day to get a representative sample.
- **Monitoring frequency and pest focus** should be directed at crop stages likely to incur economic damage. Critical stages may include seedling emergence and flowering/grain formation.
- **Sampling technique** is important to ensure a representative portion of the crop has been monitored since pest activity is often patchy. Having defined sampling parameters (e.g. number of samples per paddock and number of leaves per sample) helps sampling consistency. Actual sampling technique, including sample size and number, will depend on crop type, age and paddock size, and is often a compromise between the ideal number and location of samples and what is practical regarding time constraints and distance covered.
- **Balancing random sampling with areas of obvious damage** is a matter of common sense. Random sampling aims to give a good overall picture of what is happening in the field, but any obvious hot-spots should also be investigated. The relative proportion of hotspots in a field must be kept in perspective with less heavily infested areas.

Keeping good records

Accurately recording the results of sampling is critical for good decision making and being able to review the success of control measures (Figure 1). Monitoring record sheets should show the following:

- numbers and types of insects found (including details of adults and immature stages);
- size of insects—this is particularly important for larvae;
- date and time; and
- crop stage and any other relevant information (e.g. row spacings, weather conditions, and general crop observations).

Consider putting the data collected into a visual form that enables you to see trends in pest numbers and plant condition over time. Being able to see whether an insect population is increasing, static or decreasing can be useful in deciding whether an insecticide treatment may be required, and if a treatment has been effective. If you have trouble identifying damage or insects present, keep samples or take photographs for later reference.



Site: Camerons
Date: 15/9/06
Row spacing: 75cm

Sample (1 m row beat)	VS	S	M	L
1	8	5	1	0
2	1	1	1	0
3	3	3	0	1
4	3	2	1	0
5	2	6	0	0
Average		3.4	0.6	0.2
Adjust for 30% mortality (S*0.7)	(3.4×0.7) = 2.4			
Mean estimate of larval number (Adjusted S)+M+L	2.4 0.6 0.2 = 3.2			

Adjust for row spacing divide by row spacing (m) $\frac{3.2}{0.75}$

4.2 Density Estimate per square metre

Figure 1: *An example of a field check sheet for chickpeas, showing adjustments for field mortality and row spacings.*

Source: DAFF

Records of spray operations should include:

- date and time of day;
- conditions (wind speed, wind direction, temperature, presence of dew and humidity);
- product(s) used (including any additives);
- amount of product(s) and volume applied per hectare;
- method of application including nozzle types and spray pressure; and
- any other relevant details.

Sampling methods

Beat sheet

A beat sheet is the main tool used to sample row crops for pests and beneficial insects (Photo 1). Beat sheets are particularly effective for sampling caterpillars, bugs, aphids and mites. A standard beat sheet is made from yellow or white tarpaulin material with heavy dowel on each end. Beat sheets are generally between 1.3–1.5 m wide by 1.5–2.0 m deep (the larger dimensions are preferred for taller crops). The extra width on each side catches insects thrown out sideways when sampling and the sheet´s depth allows it to be draped over the adjacent plant row. This prevents insects being flung through or escaping through this row.

How to use the beat sheet:

- Place the beat sheet with one edge at the base of plants in the row to be sampled.
- Drape the other end of the beat sheet over the adjacent row. This may be difficult in crops with wide row spacing (one metre or more) and in this case spread the sheet across the inter-row space and up against the base of the next row.
- Using a one-metre stick, shake the plants in the sample row vigorously in the direction of the beat sheet 5—10 times. This will dislodge the insects from the sample row onto the beat sheet.
- Reducing the number of beat sheet shakes per site greatly reduces sampling precision. The use of smaller beat sheets, such as small fertiliser bags, reduces sampling efficiency by as much as 50%.

- Use the datasheets to record type, number and size of insects found on the beat sheet.
- One beat does not equal one sample. The standard sample unit is five non-consecutive one-metre long lengths of row, taken within a 20 m radius, i.e. 5 beats = 1 sample unit. This should be repeated at six locations in the field (i.e. 30 beats per field).
- The more samples that are taken, the more accurate is the assessment of pest activity, particularly for pests that are patchily distributed such as pod sucking bug nymphs.

When to use the beat sheet:

- Crops should be checked weekly during the vegetative stage and twice weekly from the start of budding onwards.
- Caterpillar pests are not mobile within the canopy, and checking at any time of the day should report similar numbers.
- Pod-sucking bugs, particularly green vegetable bugs, often bask on the top of the canopy during the early morning and are more easily seen at this time.
- Some pod-sucking bugs, such as brown bean bugs, are more flighty in the middle of the day and therefore more difficult to detect when beat sheet sampling. Other insects (e.g. mirid adults) are flighty no matter what time of day they are sampled so it is important to count them first.
- In very windy weather, bean bugs, mirids and other small insects are likely to be blown off the beat sheet.
- Using the beat sheet to determine insect numbers is difficult when the field and plants are wet.

While the recommended method for sampling most insects is the beat sheet, visual checking in buds and terminal structures may also be needed to supplement beat sheet counts of larvae and other more minor pests. Visual sampling will also assist in finding eggs of pests and beneficial insects.

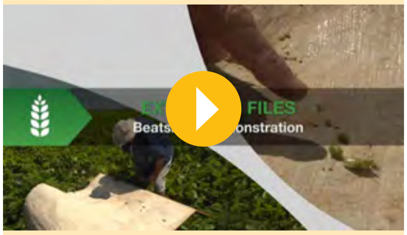
Most thresholds are expressed as pests per square metre (pests/m^2). Hence, insect counts in crops with row spacing less than one metre must be converted to pests/m^2. To do this, divide the "average insect count per row metre" across all sites by the row spacing in metres. For example, in a crop with 0.75 m (75 cm) row spacing, divide the average pest counts by 0.75.

Other sampling methods

- **Visual checking** is not recommended as the sole form of insect checking, however it has an important support role. Leaflets or flowers should be separated when looking for eggs or small larvae, and leaves checked for the presence of aphids and silverleaf whitefly. If required, dig below the soil surface to assess soil insect activity. Visual checking of plants in a crop is also important for estimating how the crop is going in terms of average growth stage, pod retention and other agronomic factors.
- **Sweep net sampling** is less efficient than beat sheet sampling and can underestimate the abundance of pest insects present in the crop. Sweep netting can be used for flighty insects and is the easiest method for sampling mirids in broadacre crops or crops with narrow row spacing (Photo 1). It is also useful if the field is wet. Sweep netting works best for smaller pests found in the tops of smaller crops (e.g. mirids in mungbeans), is less efficient against larger pests such as pod-sucking bugs, and is not practical in tall crops with a dense canopy such as coastal or irrigated soybeans. At least 20 sweeps must be taken along a single 20 m row.
- **Suction sampling** is a quick and relatively easy way to sample for mirids. Its main drawbacks are unacceptably low sampling efficiency, a propensity to suck up flowers and bees, noisy operation, and high purchase cost of the suction machine.

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. [5]

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. [6]

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 are 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.

5 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

6 GRDC. Apps, https://grdc.com.au/Resources/Apps

MORE INFORMATION

IPM Guidelines website.

IPM Guidelines for Monitoring tools and techniques.

7.3 Russian wheat aphid

Key points

- Russian wheat aphid (RWA) is found in all major cereal production regions around the world, however it has never been found in Australia before now.
- It is a major pest of cereal crops that injects toxins into the plant during feeding which retards growth and with heavy infestations, kills the plant.
- Affected plants will show whitish, yellow and red/purple leaf markings and rolling leaves.
- Russian wheat aphid is approximately 2 mm long, pale yellowish green with a fine waxy coating. The body is elongated compared with other cereal aphid species (Photo 2).

Photo 2: *The Russian wheat aphid (*Diuraphis noxia*).*

Photo: Michael Nash. Source: GRDC

According to South Australian Research and Development Institute (SARDI) entomologists, RWA is being regularly found in early-sown crops or those sown into paddocks containing volunteer cereals. In order of host preference based on overseas data, RWA tends to favour: barley, durum wheat, bread wheat, triticale, cereal rye and oats. [7]

Grain growers and advisers across the southern region are urged to monitor cereal paddocks closely for signs of damage caused by RWA.

If needed, growers should also implement a considered management strategy to control the pest.

It was recently declared not technically feasible to eradicate RWA from south-east Australia by the National Management Group (NMG) after it was first identified in a wheat crop at Tarlee in South Australia's mid north on May 13, 2016.

Since then, the aphid has been identified in many cropping regions across South Australia (Figure 2) and in the Wimmera and Mallee regions of Victoria.

7 Farming ahead (2016) Monitor RWA numbers closely over winter, http://www.farmingahead.com.au/articles/1/12169/2016-06-29/cropping/monitor-rwa-numbers-closely-over-winter

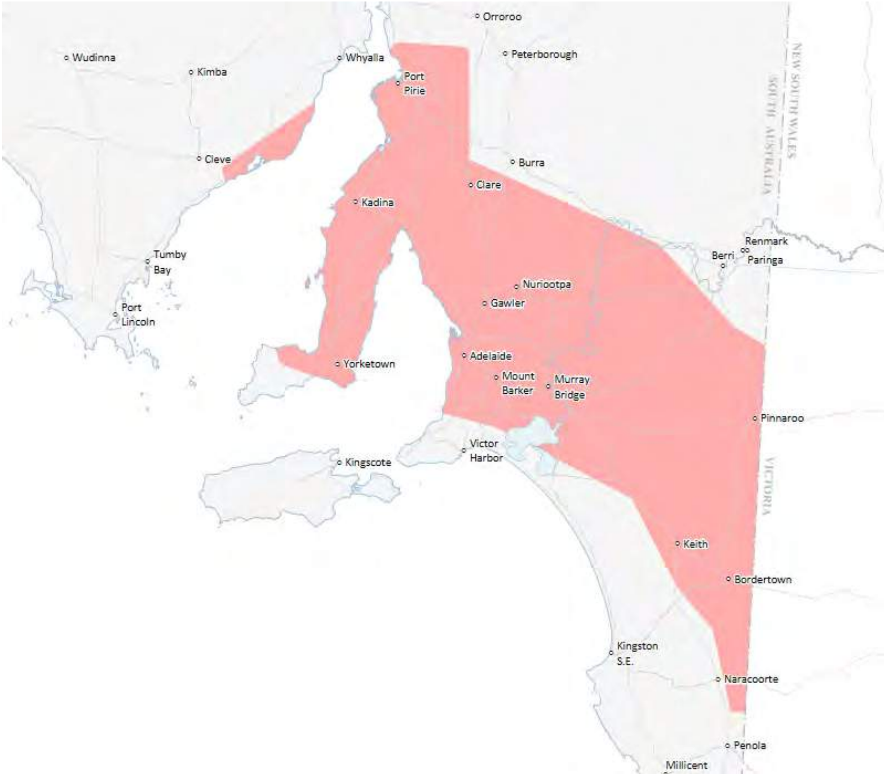


Figure 2: *Area affected by Russian Wheat Aphid in South Australia.*

Source: PIRSA

In Victoria, 48 crop samples have been confirmed for RWA infestation (Figure 3):

- 44 confirmed samples in an area bounded by Edenhope, Stawell, Bendigo, Echuca, Swan Hill, Manangatang, Patchewollock and the South Australian border.
- One sample to the west of Ararat; one sample to the west of Daylesford; one sample to the west of Werribee; and one sample to the south of Inverleigh (west of Geelong).

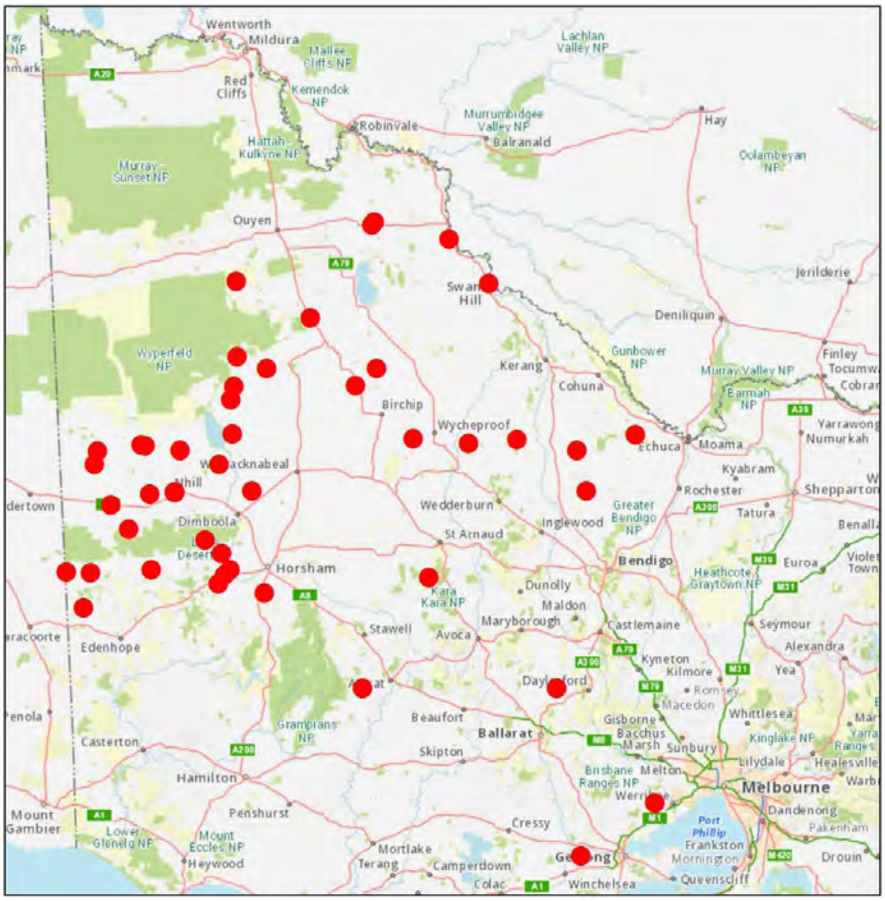


Figure 3: *Confirmed instances of Russian Wheat Aphid in Victoria.*

Source: AgVic

Following this declaration, experts are calling on growers and advisers to find, identify, consider aphid numbers and economic thresholds and enact a management strategy (FITE) if needed.

RWA is a major pest of cereal crops worldwide. It is easily spread by the wind and on live plant material.

It is asexual, meaning it does not need males and females to breed. The aphid takes about three weeks in winter and 10 to 14 days in mid-spring to reach maturity. It then continues to produce about two nymphs on a daily basis for 2—4 weeks, totalling 30—60 nymphs produced per female. This means it has a great capacity to increase numbers rapidly.

Further research is required to determine the impact of local environmental factors on RWA population dynamics. [8]

7.3.1 Damage caused by RWA

RWA differs from other common cereal aphid species in that it injects salivary toxins into the leaf of the host plant during feeding, which kills the photosynthetic chloroplasts and causes chlorosis and necrosis of the infested leaves. This retards growth and, in cases of heavy infestation, kills the plant. The effect of these toxins is localised and hence only infested leaves will show symptoms. Once the RWA infestation is controlled, new leaf growth is unaffected. [9]

8 Farming ahead (29 June 2016) Monitor RWA numbers closely over winter, http://www.farmingahead.com.au/articles/1/12169/2016-06-29/cropping/monitor-rwa-numbers-closely-over-winter

9 Farming ahead (29 June 2016) Monitor RWA numbers closely over winter, http://www.farmingahead.com.au/articles/1/12169/2016-06-29/cropping/monitor-rwa-numbers-closely-over-winter

Yield losses are proportionate to RWA abundance, measured as either percentage of plants infested or aphid numbers per shoot. According to overseas data, losses of 1 t/h occurred in plants 95% infested with RWA at GS59. In another overseas study, losses increased from 18% with 15-20 aphids per shoot to 79% with 185–205 aphids per shoot. [10]

7.3.2 Where to look and what to look for

According to South Australian Research and Development Institute (SARDI) entomologists, RWA is being regularly found in early-sown crops or those sown into paddocks containing volunteer cereals. There are also a number of grass weed and pasture hosts of RWA, including: barley grass, brome grass (particularly favourable, based on overseas information), fescue, ryegrass, wild oats, phalaris and couch grass.

Symptoms of RWA damage include longitudinal rolling of leaves where the aphids shelter and whitish, yellowish to pink-purple chlorotic streaks along the length of the leaves. These symptoms can often be confused with nutrient deficiency or herbicide damage from bleaching herbicides such as diflufenican.

RWA are approximately two millimetres long and a pale yellowish green colour with a fine, waxy coating. The lack of visible cornicles and elongated body distinguishes RWA from common cereal aphid species.

RWA can be confused with the rose grain aphid; however, it differs due to its dark or black eyes, double short "tails" (caudal processes), short antennae and apparent lack of cornicles (Figure 4).

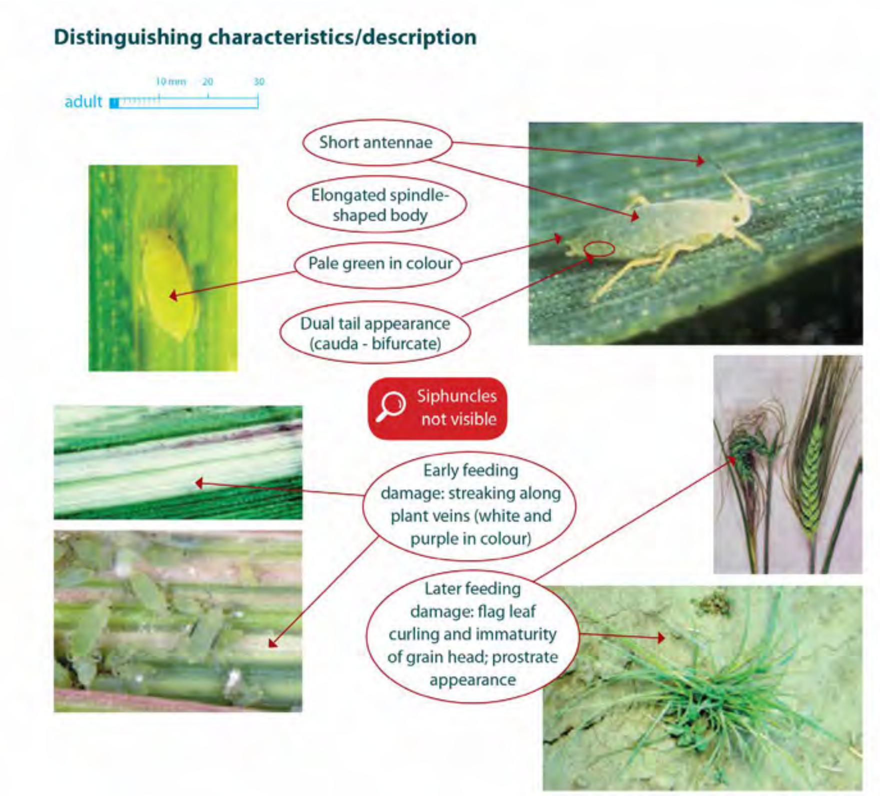


Figure 4: *Russian wheat aphid, distinguishing characteristics.*

Source: GRDC, Image from the GRDC's I SPY publication

Growers are encouraged to work with their agronomist or seek expert advice from an entomologist to help positively identify RWA if they are unsure.

10 A Lawson (2016) Monitor RWA numbers closely over winter, https://grdc.com.au/Media-Centre/GRDC-E-Newsletters/Paddock-Practices/Monitor-RWA-numbers-closely-over-winter

State agriculture departments are keen to take samples of RWA in order to build up scientific information about the pest and sample different populations.

Measures to increase the likelihood of RWA detection

- Target early sown cereal crops and volunteer cereals (and brome grass if present), particularly along crop edges.
- Follow a repeatable sampling pattern, which targets early sown and volunteer plants. A perimeter search and a 'W' shaped search pattern through each paddock will give a consistent sampling effort
- Look for RWA symptomatic plants:
- Rolling of terminal and sub-terminal leaves (Growth stage 20 and above).
- Longitudinal whitish to pink-purplish streaking of leaves (Growth stage 20 and above, Photo 3).
- Deformed "goose-neck" head as result of awn trapped by unrolled flag leaves (Growth stage 50 and above, Photo 4).

Photo 3: *Plants damaged by toxins from feeding Russian wheat aphid (Diuraphis noxia), showing stunting and longitudinal striping on tightly rolled leaves.*

Source: FAO

Photo 4: *'Fish hook' deformation of a cereal head (right), caused by feeding Russian wheat aphid compared to a normal cereal head (left).*

Source: FAO

Where to find the RWA

Search within:

- Rolled leaves, particularly in the leaf base (Photo 5).
- Leaf sheaths.
- In high numbers RWA are being found active on exposed parts at base of plants.
- At low densities, plant beating has proven successful for detection. [11]

Photo 5: *Colony of Russian wheat aphids.*

Photo: Frank Peairs. Source: PIRSA

MORE INFORMATION

Taking and submitting samples for identification.

7.3.3 Thresholds for control

While registered chemical control tactics will be important in managing infestations of RWA, growers are encouraged to consider international economic thresholds (below) as a guide for when to spray for the pest.

Whilst the economic thresholds for control still need to be determined under Australian conditions, aphid numbers should be a key consideration before making the decision to spray. The key message is to not implement prophylactic insecticide applications and to reconsider the need to spray where RWA is only present in very low numbers.

Current international advice suggests an economic threshold of 20% of plants infested up to the start of tillering and 10% of plants infested thereafter. These thresholds serve as a guide and need to be considered based upon the individual situation. The decision to spray should be based upon a wide range of factors including:

- Aphid numbers.
- Crop growth stage and time of season.
- Crop yield potential.
- Cost of the control option to be employed.
- Beneficial insect populations.
- Yield loss under Australian conditions.
- Forecast weather conditions.
- Other insect pest species present.

In the majority of cases identified in SA and Victoria to date, RWA has been present in very low numbers and infestations have been well below international economic

11 PIRSA (2016) Russian wheat aphid—paddock surveillance, http://www.pir.sa.gov.au/biosecurity/plant_health/exotic_plant_pest_emergency_response/russian_wheat_aphid

thresholds. Regular monitoring of aphid numbers through winter and spring will be required to ensure appropriate control measures may be implemented as required. Overseas data indicates that RWA is susceptible to heavy winter rainfall, and the combination of cold and wet weather will help check its build-up during mid-winter.

To ensure protection of the major yield contributing leaves it is most important to control RWA below threshold levels from the start of stem elongation, through flag leaf development and ear emergence. As a result, vigilant monitoring for RWA is encouraged during these crop stages (growth stage 30–60), and should continue through flowering to dough development. [12]

MORE INFORMATION

[Russian wheat aphid—a new pest for Australian cereal crops]

[Ramp up monitoring for Russian wheat aphid]

[Monitor RWA numbers closely over winter]

[Russian wheat aphid—Plant health Australia]

[Russian wheat aphid reporting sheet (PDF, 279.7 KB)]

[Exotic Pest Alert: Identification of Russian wheat aphid and associated damage]

[PIRSA Russian wheat aphid—Paddock decontamination protocol (DOC, 197 KB)]

[RWA Distribution Map]

7.3.4 Management of RWA

Control options

An emergency Australian Pesticides and Veterinary Medicines Authority (APVMA) permit (PER82792) has been issued for the use of products containing 500 g/L chlorpyrifos (rate: 1.2 L/ha), with a LI700 surfactant (rate: 240 ml/ha), and products containing 500 g/kg pirimicarb (rate: 200-250 g/ha) to control RWA in winter cereals.

An Australian Pesticides and Veterinary Medicines Authority (APVMA) permit (PER82304) has been issued for the use of products containing 600 g/L IMIDACLOPRID as their only active constituent. Application rate 120 mL product / 100 kg seed. This is for seed treatment only for the control of RWA in winter cereals.

The permit must be read and understood by all persons operating in accordance with it.

The Australian Pesticides and Veterinary Medicines Authority (APVMA) have issued an emergency permit (82792) for growers to control Russian wheat aphid.

- Permit 82792

A new permit has been issued by the Australian Pesticides and Veterinary Medicines Authority (APVMA) for growers to control Russian wheat aphid during seed treatment over winter.

- Permit 82304

Chemical users must read and understand all sections of chemical labels and permits prior to use. There are numerous statements (e.g. DO NOT statements) on product labels that are critical in the managing risks associated with the use of chemicals. Examples of such statements include:

- DO NOT spray any plants in flower while bees are foraging.
- DO NOT re-apply to the same crop within seven days (unless specifically recommended in the directions for Use).
- DO NOT apply if heavy rains or storms that are likely to cause surface runoff are forecast in the immediate area within two days of application.
- DO NOT allow animals or poultry access to treated area within three days of application.

Bees

As for all field chemical use, it is recommended that users consider the risks of chemical use to bees that may be present in the local area. Chemical users are encouraged to contact hive owners as soon as possible so that they can take appropriate steps to minimise the risks to their hives.

Contact details can generally be found on the hive(s) or you can contact the land owner on which the hives are located.

General instructions

- Read and follow the APVMA permit and labels of associated chemical products.

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12 A Lawson (2016) Monitor RWA numbers closely over winter, https://grdc.com.au/Media-Centre/GRDC-E-Newsletters/Paddock-Practices/Monitor-RWA-numbers-closely-over-winter

VIDEOS

WATCH: GCTV20: Russian wheat aphid—recommendations for ongoing treatment.

WATCH: Integrated pest management to combat the Russian wheat aphid.

- Ensure all DO NOT statements and relevant Withholding Periods, Export Slaughter Intervals (ESIs) and Export Grazing Interval (EGIs) are observed.
- Adopt best-practice farm hygiene procedures to retard the spread of the pest between fields and adjacent properties.
- Keep traffic out of affected areas and minimise movement in adjacent areas. [13]

7.4 Aphids

Aphids are usually regarded as a minor pest of winter cereals, but in some seasons they can build up to very high densities. 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.

Four different species of aphid can infest winter cereals:

1. Oat or wheat aphid
2. Corn aphid
3. Rose-grain aphid
4. Rice root aphid

Aphids are a group of soft-bodied bugs commonly found in a wide range of crops and pastures. Identification of crop aphids is very important when making control decisions. Distinguishing between aphids can be easy in the non-winged form but challenging with winged aphids. See a pictorial guide to distinguishing winged aphids.

7.4.1 Oat or wheat aphid

The oat aphid is a relatively common aphid that is most prevalent in wheat and oats. This aphid has an olive green body with a characteristic rust-red patch on the end of the abdomen. Oat aphids are an important vector of barley yellow dwarf virus (BYDV). They can affect cereals by spreading BYDV as well as by direct feeding damage to plants when in sufficient numbers. When populations exceed thresholds, the use of targeted spraying with selective insecticides is recommended.

The oat aphid is an introduced species that is a common pest of cereals and pasture grasses. They are widespread and found in all states of Australia. Oat aphids typically colonise the lower portion of plants, with infestations extending from around the plant's base, up on to the leaves and stems.

Oat aphids vary in colour from olive-green to greenish black and are usually identifiable by a dark rust-red patch on the tip of the abdomen, although under some conditions this is not apparent. Adults are approximately 2 mm long, pear-shaped and have antennae that extend half the body length (Figure 5). Adults may be winged or wingless and tend to develop wings when plants become overcrowded or unsuitable. [14]

13 Agriculture Victoria (2016) RWA treatment factsheet. http://agriculture.vic.gov.au/__data/assets/word_doc/0017/321164/Final-RWA-Treatment-Factsheet.docx-.docx

14 P Umina, S Hangartner (2015) Oat aphid. Cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

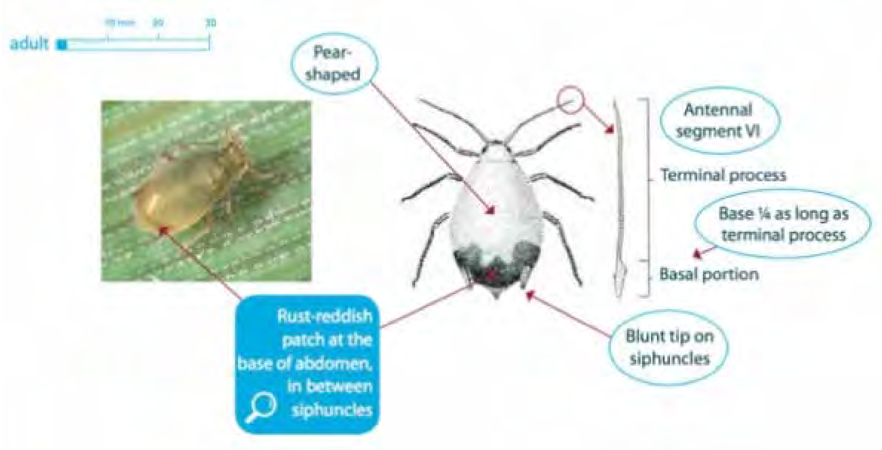

Figure 5: *Distinguishing characteristics of oat or wheat aphids.*

Source: Bellati et al. (2012), in Cesar

7.4.2 Corn aphid

Corn aphids are introduced, and are a relatively minor pest of cereal crops. They attack all crop stages but most damage occurs when high populations infest cereal heads. Corn aphids are most prevalent in years when there is an early break to the season followed by mild weather conditions in autumn. Corn aphids transmit a number of plant viruses, which can cause significant yield losses.

Corn aphids are light green to dark green, with two darker patches at the base of each cornicle (siphuncle). Adults grow up to 2 mm long, have an oblong-shaped body and antennae that extend to about a third of the body length (Figure 6. The legs and antennae are typically darker in colour.

Nymphs are similar to adults but smaller in size and always wingless, whereas adults may be winged or wingless. [15]

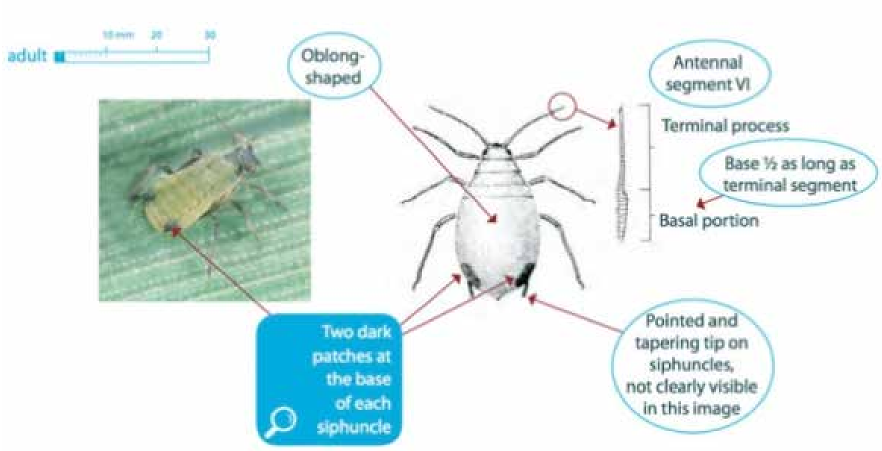

Figure 6: *Distinguishing characteristics of corn aphids.*

Source: Bellati et al. (2012) in Cesar

7.4.3 Rose-grain aphid

Rose-grain aphids are an introduced species that has been recorded in SA, Victoria, Tasmania, NSW and Queensland.

15 P Umina, S Hangartner (2015) Oat aphid. Cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Corn-aphid

Adults and nymphs are sapsuckers. Under heavy infestations, plants may turn yellow and appear unthrifty. Rose-grain aphids can spread barley yellow dwarf virus in wheat and barley.

Adults are 3 mm long, green to yellow-green with long and pale siphunculi (tube-like projections on either side at the rear of the body) and may have wings (Photo 6). There is a dark green stripe down the middle of the back. Antennae reach beyond the base of the siphunculi. Nymphs are similar but smaller. Because of its distinctive colour, it is unlikely to be confused with other aphids.

Photo 6: *Adult Rose-grain aphid with nymphs.*

Source: QDAFF

7.4.4 Conditions favouring aphid development

Aphids can be found all year round, often persisting on a range of volunteer grasses and self-sown cereals during summer and early autumn. Winged aphids fly into crops from grass weeds, pasture grasses or other cereal crops, and colonies of aphids start to build up within the crop.

Aphids are most prevalent on cereals in late winter and early spring. High numbers often occur in years when there is an early break in the season and mild weather in autumn and early winter provide favourable conditions for colonisation and multiplication.

- Oat aphid—basal leaves, stems and back of ears of wheat, barley, oats.
- Corn aphid—inside the leaf whorl of the plant; cast skins indicate their presence; seldom on wheat or oats.
- Grain aphid—colonises the younger leaves and ears of wheat, oats and barley;
- Rose-grain aphid—underside of lower leaves and moves upwards as these leaves die. [16]

Aphids can reproduce both asexually and sexually, however, in Australia, the sexual phase is often lost. Aphids reproduce asexually whereby females give birth to live young.

Temperatures during autumn and spring are optimal for aphid survival and reproduction. During these times, the aphid populations may undergo several generations. Populations peak in late winter and early spring; development rates are particularly favoured when daily maximum temperatures reach 20–25°C.

16 IPM Guidelines (2016) Aphids in winter cereals, http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-winter-cereals/

Young wingless aphid nymphs develop through several growth stages, moulting at each stage into a larger individual. Plants can become sticky with honeydew excreted by the aphids. When plants become unsuitable or overcrowding occurs, the population produces winged aphids (alates), which can migrate to other plants or crops.

7.4.5 Thresholds for control

When determining economic thresholds for aphids, it is critical to consider several other factors before making a decision. Most importantly, the current growing conditions and moisture availability should be assessed. Crops that are not moisture stressed have a greater ability to compensate for aphid damage and will generally be able to tolerate far higher infestations than moisture stressed plants before a yield loss occurs.

Recommended control rates are more than 15 aphids per tiller on 50% of tillers if the expected yield will exceed 3 t/ha.

Thresholds for managing aphids to prevent the incursion of aphid-vectored virus have not been established and will be much lower than any threshold to prevent yield loss via direct feeding. [17]

Aphid populations can decline rapidly, which may make control unnecessary. In many years, aphid populations will not reach threshold levels.

7.4.6 Managing aphids

Though aphid numbers are rarely high enough to warrant control, it is important to know the critical periods for aphid management (Figure 7).

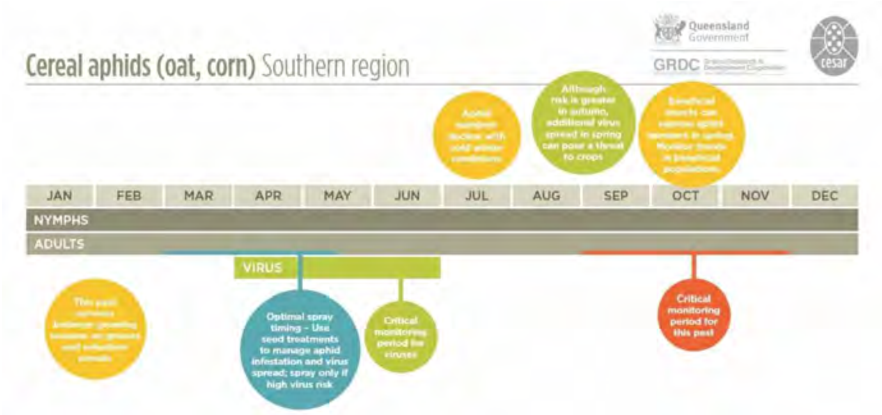

Figure 7: *Lifecycles, critical monitoring and management periods for cereal aphids in the southern region of Australia.*

Source: cesar and QDAFF

Biological control

There are many effective natural enemies of aphids. Hoverfly larvae, lacewings, ladybird beetles and damsel bugs are known predators that can suppress populations. Aphid parasitic wasps lay eggs inside bodies of aphids and evidence of parasitism is seen as bronze-coloured enlarged aphid "mummies". As mummies develop at the latter stages of wasp development inside the aphid host, it is likely that many more aphids have been parasitized than indicated by the proportion of mummies. Naturally occurring aphid fungal diseases (*Pandora neoaphidis* and *Conidiobolyus obscurus*) can also suppress aphid populations.

17 P Umina, S Hangartner (2015) Oat aphid. Cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

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.

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. [18]

Monitoring

Monitor all crop stages from seedling stage onwards. Look on leaf sheaths, stems, within whorls and heads, and record the number of large and small aphids (adults and juveniles), beneficials (including parasitised mummies), and the impact of the infestation on the crop.

Stem elongation to late flowering is the most vulnerable stage. Frequent monitoring is required to detect rapid increases of aphid populations.

Check regularly—at least five points in the field and sample 20 plants at each point. Populations may be patchy—densities at crop edges may not be representative of the whole field.

Average number of aphids per stem/tiller samples gives a useful measurement of their density. Repeated sampling will provide information on whether the population is increasing (lots of juveniles relative to adults), stable, or declining (lots of adults and winged adults). [19]

7.5 Mites

7.5.1 Redlegged earth mite

The redlegged earth mite (*Halotydeus destructor*) (RLEM) is a major pest of pastures, crops and vegetables in regions of Australia with cool wet winters and hot dry summers, costing the Australian grains industry approximately $44.7 million per year. [20] 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.

18 P Umina, S Hangartner (2015) Oat aphid. Cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Oat-aphid

19 IPM Guidelines (2016) Aphids in winter cereals, http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-winter-cereals/

20 GRDC (2013) Ground cover supplement—emerging issues with diseases, weeds and pests.

The RLEM is widespread throughout most agricultural regions of southern Australia. They are found in southern NSW, on the east coast of Tasmania, the south-east of SA, the south-west of WA and throughout Victoria (Figure 8). 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.

Figure 8: *The known distribution of redlegged earth mites in Australia.*

Source: Cesar

Adult RLEM are 1 mm in length and 0.6 mm wide (the size of a pin head) with 8 red-orange legs and a completely black velvety body (Figure 9). Newly hatched mites are pinkish-orange with 6 legs, are only 0.2 mm long and are not generally visible to the untrained eye. The larval stage is followed by three nymphal stages in which the mites have 8 legs and resemble the adult mite, but are smaller and sexually undeveloped.

Other mite pests, in particular blue oat mites and the balaustium mite, are sometimes confused with RLEM in the field. Blue oat mites can be distinguished from RLEM by an oval orange/reddish mark on their back, while the balaustium mite has short hairs covering its body and can grow to twice the adult size of RLEM. Unlike other species that tend to feed singularly, RLEM generally feed in large groups of up to 30 individuals.

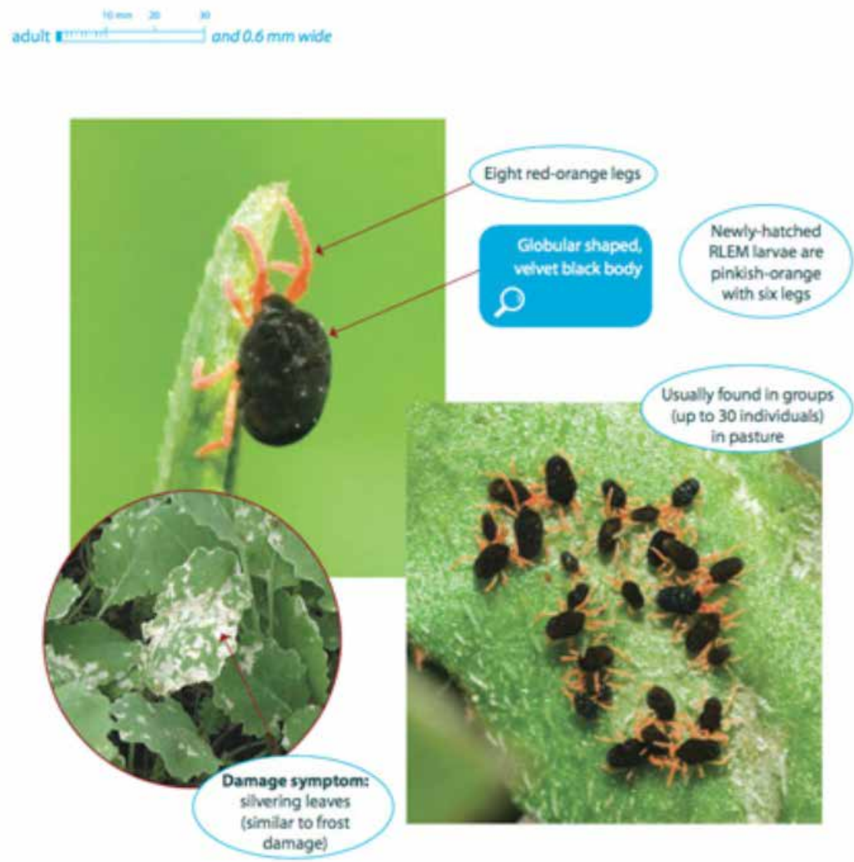

Figure 9: *Distinguishing characteristics of RLEM.*

Source: Bellati et al. (2012) in cesar

Damage caused by RLEM

Typical mite damage appears as "silvering" or "whitening" of the attacked foliage. Mites use adapted mouthparts to lacerate the leaf tissue of plants and suck up the discharged sap. The resulting cell and cuticle damage promotes desiccation, retards photosynthesis and produces the characteristic silvering that is often mistaken as frost damage. RLEM are most damaging to newly establishing pastures and emerging crops, greatly reducing seedling survival and development. In severe cases, entire crops may need re-sowing following RLEM attack.

RLEM hosts include pasture legumes, subterranean and other clovers, medics and lucerne. They are particularly damaging to seedlings of all legumes, oilseeds and lupins when in high numbers. They feed on ryegrass and young cereal crops, especially oats. RLEM also feed on a range of weed species including Patersons' curse, skeleton weed, variegated thistle, ox-tongue, smooth cats' ear and capeweed.

RLEM feeding reduces the productivity of established plants and has been found to be directly responsible for reduction in pasture palatability to livestock.

Managing RLEM

It is important to know the critical periods for RLEM management (Figure 10).

Figure 10: *Critical periods for managing RLEM.*

Source: cesar

Carefully inspect susceptible pastures and crops from autumn to spring for the presence of mites and evidence of damage. It is especially important to inspect crops regularly in the first three to five weeks after sowing. Mites are best detected feeding on the leaves in the morning or on overcast days. In the warmer part of the day RLEM tend to gather at the base of plants, sheltering in leaf sheaths and under debris. They will crawl into cracks in the ground to avoid heat and cold. When disturbed during feeding they will drop to the ground and seek shelter.

RLEM compete with other pasture pests, such as blue oat mites, for food and resources. Competition within and between mite species has been demonstrated in pastures and on a variety of crop types. This means control strategies that only target RLEM may not entirely remove pest pressure because other pests can fill the gap. This can be particularly evident after chemical applications, which are generally more effective against RLEM than other mite pests.

Chemical control

Chemicals are the most commonly used control option against earth mites. While a number of chemicals are registered for control of active RLEM in pastures and crops, there are no currently registered pesticides that are effective against RLEM eggs.

Autumn sprays:

Controlling first generation mites before they have a chance to lay eggs is the only effective way to avoid the need for a second spray. Hence, pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, before adults begin to lay eggs. Timing of chemical application is critical.

Pesticides with persistent residual activity can be used as bare earth treatments, either pre-sowing or at sowing to kill emerging mites. This will protect seedlings, which are most vulnerable to damage.

Foliage sprays are applied once the crop has emerged and are generally an effective method of control.

Systemic pesticides are often applied as seed dressings. Seed dressings act by maintaining the pesticide at toxic levels within the growing plant, which then affects mites as they feed. This strategy aims to minimise damage to plants during the sensitive establishment phase. However, if mite numbers are high, plants may suffer significant damage before the pesticide has much effect.

Spring sprays:

Research has shown that one accurately timed spring spray of an appropriate chemical can significantly reduce populations of RLEM the following autumn. This approach works by killing mites before they start producing diapause eggs in mid-late spring. The optimum date can be predicted using climatic variables and tools such as TIMERITE® can help farmers identify the optimum date for spraying. Spring RLEM sprays will generally not be effective against other pest mites.

Repeated successive use of the “spring spray” technique is not recommended as this could lead to populations evolving resistance to the strategy. To prevent the development of resistance, the selective rotation of products with different Modes of Action is advised.

Biological control

There is evidence of natural RLEM populations showing resistance to some chemicals; therefore, alternative management strategies are needed to complement current control methods.

At least 19 predators and one pathogen are known to attack earth mites in eastern Australia. The most important predators of RLEM appear to be other mites, although small beetles, spiders and ants also play a role in reducing populations. A predatory mite (*Anystis wallacei*) has been introduced as a means of biological control; however, it has slow dispersal and establishment rates. Although locally successful, the benefits of this mite are yet to be demonstrated.

Preserving natural enemies may prevent RLEM population explosions in established pastures, but this is often difficult to achieve. This is mainly because the pesticides generally used to control RLEM are broad-spectrum and kill beneficial species as well as the pests. The chemical impact on predator species can be minimised by choosing a spray that has least impact and by reducing the number of chemical applications. Although there are few registered alternatives for RLEM, there are groups that have low-moderate impacts on many natural enemies such as cyclodienes.

Natural enemies residing in windbreaks and roadside vegetation have been demonstrated to suppress RLEM in adjacent pasture paddocks. When pesticides with residual activity are applied as border sprays to prevent mites moving into a crop or pasture, beneficial insect numbers may be inadvertently reduced, thereby protecting RLEM populations.

Cultural control

Using cultural control methods can decrease the need for chemical control. Rotating crops or pastures with non-host crops can reduce pest colonisation, reproduction and survival. For example, prior to planting a susceptible crop like 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 into pastures with a high clover content be avoided.

Appropriate grazing management can reduce RLEM populations to below damaging thresholds, possibly because shorter pasture results in lower relative humidity, which increases mite mortality and limits food resources.

Other cultural techniques including modification of tillage practices, trap or border crops, and mixed cropping can reduce overall infestation levels to below the economic control threshold, particularly when employed in conjunction with other measures. [21]

VIDEOS

WATCH: Green peach aphid and redlegged earth mite resistance in Australia's southern cropping region.

21 P Umina (2007) Redlegged earth mite, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/?a=223443

7.5.2 Balaustium mite

The *Balaustium* mite, *Balaustium medicagoense* (Acari: Erythreidae), has recently been identified within the Australian grains industry as an emerging pest of winter crops and pasture. This mite is the only species of the genus *Balaustium* recorded in Australia and was probably introduced from South Africa, along with the redlegged earth mite (*Halotydeus destructor*), in the early 1900s. *Balaustium* mites are found throughout areas of southern Australia that have a Mediterranean-type climate, attacking a variety of agriculturally important plants.

They are sporadically found in areas with a Mediterranean climate in Victoria, NSW, SA and WA (Figure 11). They have also been found in Tasmania although their exact distribution is unclear. *Balaustium* mites are typically active from March to November, although mites can persist on green feed during summer if available.

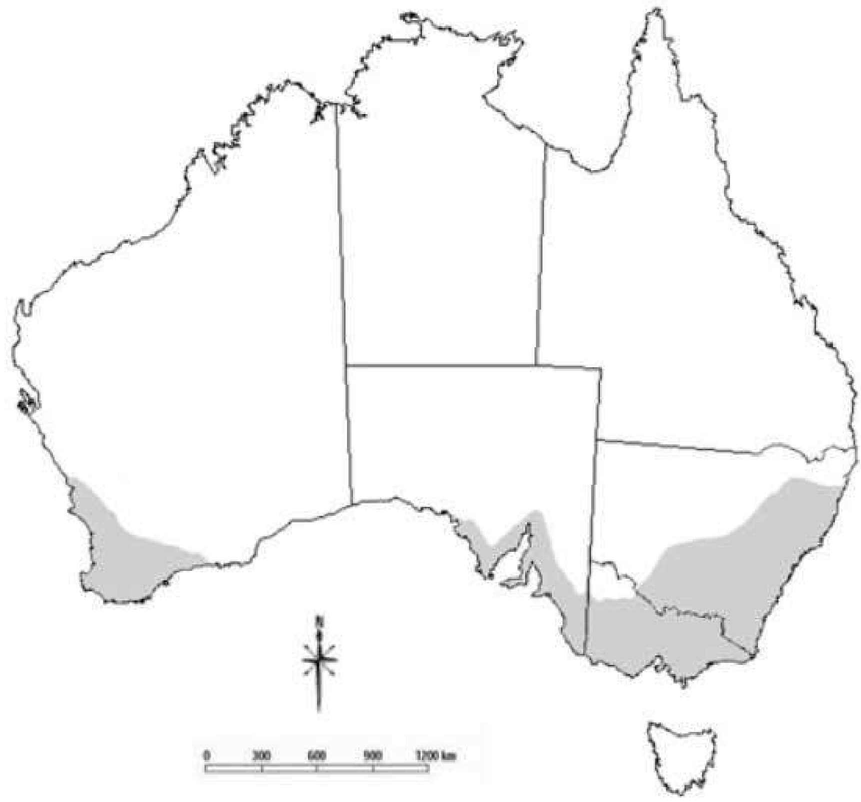

Figure 11: *The known distribution of Balaustium mites in Australia.*

Source: cesar

Balaustium mites are quite often confused with other pest mites, such as the redlegged earth mite and blue oat mites (*Penthaleus* spp.). They have a rounded dark red/brown coloured body and red legs similar to other pest mites, however they have distinct short stout hairs covering their entire body giving them a velvety appearance (Figure 12). 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.

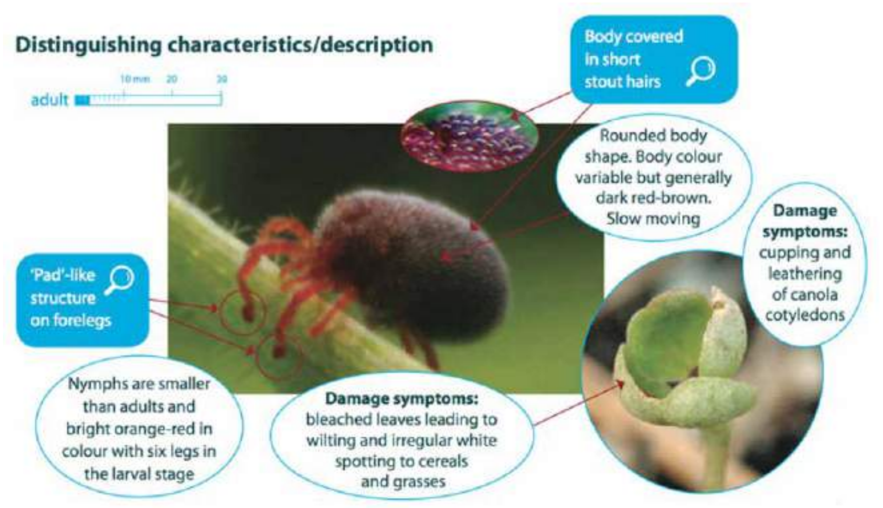

Figure 12: *Adult Balaustium mite.*

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. [22]

Damage caused by Balaustium mite

Balaustium mites feed on plants using their adapted mouthparts to probe leaf tissue of plants and suck up sap. In most situations *Balaustium* mites cause little damage, however when numbers are high and plants are already stressed due to other environmental conditions, significant damage to crops can occur. Under high infestations, seedlings or plants can wilt and die. *Balaustium* mites typically attack leaf edges and leaf tips of plants.

There are no economic thresholds for this pest.

Management

It is important to know the critical periods for *Balaustium* mite management (Figure 13).

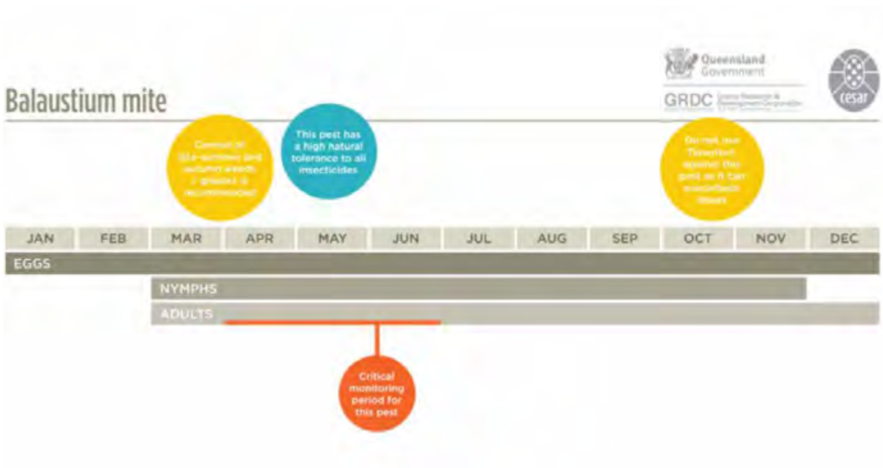

Figure 13: *Critical periods for Balaustium management.*

Source: cesar

22 D Grey (2010) Balaustium mite. Agriculture Victoria , http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/balaustium-mite

Monitoring

The impact of mite damage is increased when plants are under stress from adverse conditions such as prolonged dry weather or waterlogged soils. Ideal conditions for seedling growth enable plants to tolerate higher numbers of *Balaustium* mites. Carefully inspect susceptible pastures and crops from autumn to spring for the presence of mites and evidence of damage. It is especially important to inspect crops regularly in the first three to five weeks after sowing.

Crops sown into paddocks that were pasture the previous year should be regularly inspected for *Balaustium* mites. Weeds present in paddocks prior to cropping should also be checked for the presence and abundance of *Balaustium* mites. Mites are best detected feeding on the leaves, especially on or near the tips, during the warmest part of the day. *Balaustium* mites are difficult to find when conditions are cold and/or wet.

One of the most effective methods to sample mites is using a D-vac, which is based on the vacuum principle—much like a vacuum cleaner used in the home. Typically, a standard petrol powered garden blower/vacuum machine is used, such as those manufactured by Stihl® or Ryobi®. A sieve is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface.

Control

Currently no product has been registered to control *Balaustium* mite in any state or territory of Australia. The Australian Pesticides and Veterinary Medicine Authority (APVMA) maintain a database of all chemicals registered for the control of agricultural pests in Australia. Reference to the APVMA website will confirm the registration status of products for *Balaustium* mite, or consult chemical resellers or a local chemical standards officer.

Ensure the relevant Maximum Residue Limits (MRLs) for the chemical in the end market is met, be it domestic or export.

Chemical users must read and understand all sections of chemical labels prior to use.

There have been no biological control agents (predators or parasites) identified in Australia that are effective in controlling *Balaustium* mites. Alternative methods such as cultural control can be effective at controlling this mite. Early control of summer weeds, within and around paddocks, especially capeweed and grasses, can help prevent mite outbreaks. Rotating crops or pastures with non-host crops can also reduce pest colonisation, reproduction and survival. For example, prior to planting a susceptible crop like cereals or canola, a paddock could be sown to a broadleaf plant that *Balaustium*mites have not been reported to attack, such as vetch. [23]

7.5.3 Blue oat mite

Blue oat mites (BOM) (*Penthaleus spp.*) are species of earth mites, which are major agricultural pests of southern Australia and other parts of the world, attacking various pasture, vegetable and crop plants. BOM were introduced from Europe and first recorded in NSW in 1921. Management of these mites in Australia has been complicated by the recent discovery of three distinct species of BOM, whereas prior research had assumed just a single species.

Blue oat mites are important crop and pasture pests in southern Australia. They are commonly found in Mediterranean climates of Victoria, NSW, SA, WA and eastern Tasmania (Figure 14). There are three main species of BOM: *Penthaleus major*, *Penthaleus falcatus* and *Penthaleus tectus*. These species differ in their distributions.

23 D Grey (2010) Balaustium mite. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/balaustium-mite

Figure 14: *The known distribution of blue oat mites in Australia.*

Source: cesar

Adult BOM are 1 mm in length and approximately 0.7–0.8 mm wide, with 8 red-orange legs. They have a blue-black coloured body with a characteristic red mark on their back (Figure 15). 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 15: *Distinguishing characteristics of Blue oat mite.*

Source: Bellati et al. (2012) in cesar

BOM are often misidentified as redlegged earth mites (RLEM) in the field, which has meant that the damage caused by BOM has been under-represented. Despite having a similar appearance, RLEM and BOM can be readily distinguished from each other. RLEM have a completely black coloured body and tend to feed in larger groups of up to 30 individuals. BOM have the red mark on their back and are usually found singularly or in very small groups.

Damage caused by BOM

Feeding causes silvering or white discoloration of leaves and distortion, or shrivelling in severe infestations. Affected seedlings can die at emergence with high mite populations. Unlike redlegged earth mites, blue oat mites typically feed singularly or in very small groups.

Mites use adapted mouthparts to lacerate the leaf tissue of plants and suck up the discharged sap. Resulting cell and cuticle destruction promotes desiccation, retards photosynthesis and produces the characteristic silvering that is often mistaken as frost damage (Photo 7). BOM are most damaging to newly establishing pastures and emerging crops, greatly reducing seedling survival and retarding development.

Photo 7: *Typical Blue oat mite damage to leaf.*

Source: AgVic

Young mites prefer to feed on the sheath leaves or tender shoots near the soil surface, while adults feed on more mature plant tissues. BOM feeding reduces the productivity of established plants and is directly responsible for reductions in pasture palatability to livestock. Even in established pastures, damage from large infestations may significantly affect productivity.

The impact of mite damage is increased when plants are under stress from adverse conditions such as prolonged dry weather or waterlogged soils. Ideal growing conditions for seedlings enable plants to tolerate higher numbers of mites.

Managing BOM

It is important to know the critical periods for BOM management (Figure 16).

Figure 16: *Critical time periods for managing BOM.*

Source: cesar

Chemical control

Chemicals are the most common method of control against earth mites. Unfortunately, all currently registered pesticides are only effective against the active stages of mites; they do not kill mite eggs.

While a number of chemicals are registered in pastures and crops, differences in tolerance levels between species complicates management of BOM. *P. falcatus* has a high natural tolerance to a range of pesticides registered against earth mites in Australia and is responsible for many control failures involving earth mites. The other BOM species have a lower level of tolerance to pesticides and are generally easier to control with chemicals in the field.

Chemical sprays are commonly applied at the time of infestation, when mites are at high levels and crops already show signs of damage. Control of first generation mites before they can lay eggs is an effective way to avoid a second spray. Hence, pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, as adults will then begin laying eggs. While spraying pesticides in spring can greatly reduce the size of RLEM populations the following autumn, this strategy will generally not be as effective for the control of BOM.

Pesticides with persistent residual effects can be used as bare-earth treatments. These treatments can be applied prior to, or at sowing to kill emerging mites and protect the plants throughout their seedling stage.

Systemic pesticides are often applied as seed dressings to maintain the pesticide at toxic levels within the plants as they grow. This can help minimise damage to plants during the sensitive establishment phase, however, if mite numbers are high, significant damage may still occur before the pesticide has much effect.

To prevent the buildup of resistant populations, spray pesticides only when necessary and rotate pesticides from chemical classes with different modes of action. To avoid developing multiple pesticide resistance, rotate chemical classes across generations rather than within a generation.

Information on the registration status, rates of application and warnings related to withholding periods, OH&S, residues and off-target effects should be obtained before making decisions on which pesticide to use. This information is available from the DEPI Chemical Standards Branch, chemical resellers, APVMA and the pesticide manufacturer. Always consult the label and MSDS before using any pesticide.

Biological & cultural control

Integrated pest management programs can complement current chemical control methods by introducing non-chemical options, such as cultural and biological control.

Although no systematic survey has been conducted, a number of predator species are known to attack earth mites in Australia. The most important predators of BOM appear to be other mites, although small beetles, spiders and ants may also play a role. The French anystis mite is an effective predator but is limited in distribution. Snout mites will also prey upon BOM, particularly in pastures. The fungal pathogen, *Neozygites acaracida*, is prevalent in BOM populations during wet winters and could be responsible for observed “population crashes”.

Preserving natural enemies when using chemicals is often difficult because the pesticides generally used are broad-spectrum and kill beneficial species as well as the pests. Impact on natural enemies can be reduced by using a pesticide that has the least impact and by minimising the number of applications. Although there are few registered alternatives for BOM control, there are groups such as the chloronicotinyls, which are used in some seed treatments that have low–moderate impacts on many natural enemies.

Cultural controls such as rotating crops or pastures with non-host crops can reduce pest colonisation, reproduction and survival, decreasing the need for chemical control. When *P. major* is the predominant species, canola and lentils are potentially useful rotation crops, while pastures containing predominantly thick-bladed grasses should be carefully monitored and rotated with other crops. In situations where *P. falcatus* is the most abundant mite species, farmers can consider rotating crops with lentils, while rotations that involve canola may be the most effective means of reducing the impact of *P. tectus*.

Many cultural control methods for BOM can also suppress other mite pests, such as RLEM. Cultivation will significantly decrease the number of over-summering eggs, while hot stubble burns can provide a similar effect. Many broad-leaved weeds provide an alternative food source, particularly for juvenile stages. As such, clean fallowing and the control of weeds within crops and around pasture perimeters, especially of bristly ox tongue and cats ear, can help reduce BOM numbers.

Appropriate grazing management can also reduce mite populations to below damaging thresholds. This may be because shorter pasture results in lower relative humidity, which increases mite mortality and limits food resources. Grazing pastures in spring to less than 2 t/ha Feed On Offer (dry weight), can reduce mite numbers to low levels and provide some level of control the following year. [24]

7.5.4 *Bryobia* mite

There are over 100 species of *Bryobia* mite worldwide, with at least seven found in Australian cropping environments. Unlike other broadacre mite species, which are typically active from autumn to spring, *Bryobia* mites prefer the warmer months of the year. *Bryobia* mites are smaller than other commonly occurring pest mites. They attack pastures and numerous winter crops earlier in the season.

Bryobia mites (sometimes referred to as clover mites) are sporadic pests typically found in warmer months of the year, from spring through to autumn. They are unlikely to be a problem over winter, however they can persist throughout all months of the year. They are broadly distributed throughout most agricultural regions in southern Australia with a Mediterranean-type climate, including Victoria, SA, NSW and WA (Figure 17). They have also been recorded in Tasmania and Queensland.

Figure 17: *Known distribution of* Bryobia *mites in Australia*

Source: cesar

There are at least seven species of *Bryobia* mites found in broadacre crops in Australia. These appear very similar. *Bryobia* mites are smaller than other commonly

24 Agriculture Victoria (2007) Blue oat mite, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite

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 18).

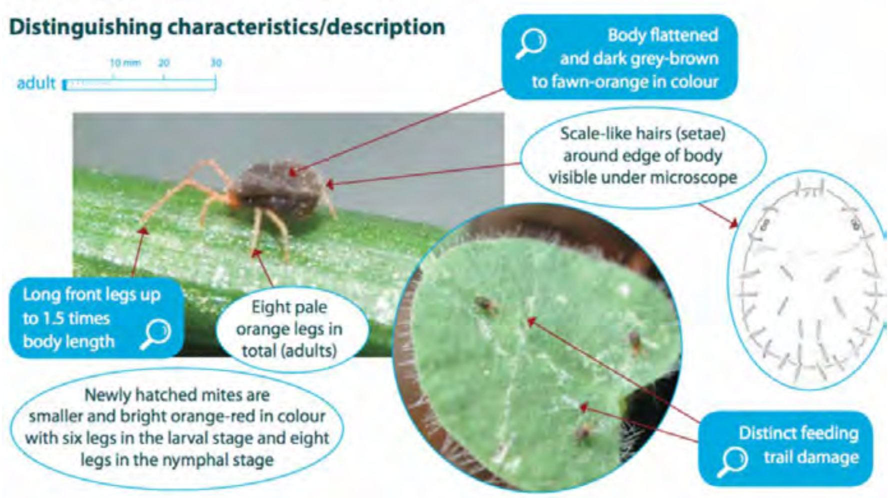

Figure 18: *Distinguishing characteristics of Bryobia mites.*

Source: Bellati et al. (2012) in cesar

Damage cause by mite

Bryobia mites tend to cause most damage in autumn when they attack newly establishing pastures and emerging crops, greatly reducing seedling survival and retarding development. They feed on the upper surfaces of leaves and cotyledons by piercing and sucking leaf material. This feeding causes distinctive trails of whitish-grey spots on leaves. Extensive feeding damage can lead to cotyledons shriveling. On grasses, Bryobia mite feeding can resemble that of redlegged earth mites.

There are no economic thresholds for control.

Managing Bryobia mites

It is important to know the critical periods for Bryobia mite management (Figure 19).

Figure 19: *Critical time periods for managing Bryobia mite.*

Source: cesar

Biological

There are currently no known biological control agents for *Bryobia* mites in Australia.

Cultural

Crops that follow pastures with a high clover content are most at risk. Avoid planting susceptible crops such as canola, lupins, vetch and lucerne into these paddocks. Early control of summer and autumn weeds within and around paddocks, especially broadleaf weeds such as capeweed and clovers, can help prevent mite outbreaks.

Chemical

Some insecticides are registered for *Bryobia* mites, however, be aware that recommended rates used against other mites might be ineffective against *Bryobia* mites. *Bryobia* mites have a natural tolerance to several chemicals. Insecticides do not kill mite eggs. Generally, organophosphate insecticides provide better control against *Bryobia* mites than synthetic pyrethroids. [25]

7.6 Lucerne flea

The lucerne flea, *Sminthurus viridis* (Collembola: Sminthuridae), is a springtail that is found in both the northern and southern hemispheres but is restricted to areas that have a Mediterranean-type climate. It is thought to have been introduced to Australia from Europe and has since become a significant agricultural pest of crops and pastures across the southern states. It is not related to the fleas, which attack animals and humans.

Lucerne fleas are common pests found in Victoria, Tasmania, SA, NSW and WA (Figure 20). Higher numbers are often found in the winter rainfall areas of southern Australia, including Tasmania, or in irrigation areas where moisture is plentiful. They are generally more problematic on loam/clay soils. Lucerne fleas are often patchily distributed within paddocks and across a region.

Figure 20: *The known distribution of the Lucerne flea in Australia.*

Source: cesar

25 P Umina, S Hangartner, G McDonald (2015) Bryobia mite, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Bryobia-mite

The lucerne flea is a springtail—this is a group of arthropods that have six or fewer abdominal segments and a forked tubular appendage or furcula under the abdomen. Springtails are one of the most abundant of all macroscopic insects and are frequently found in leaf litter and other decaying material, where they are primarily detritivores. Very few species, including the lucerne flea, are regarded as crop pests around the world.

The adult lucerne flea is approximately 3 mm long, light green-yellow in colour and often with mottled darker patches over the body. They are wingless and have enlarged, globular shaped abdomens (Figure 21). They are not related to true fleas. Newly hatched nymphs are pale yellow and 0.5–0.75 mm long, and as they grow they resemble adults, but are smaller.

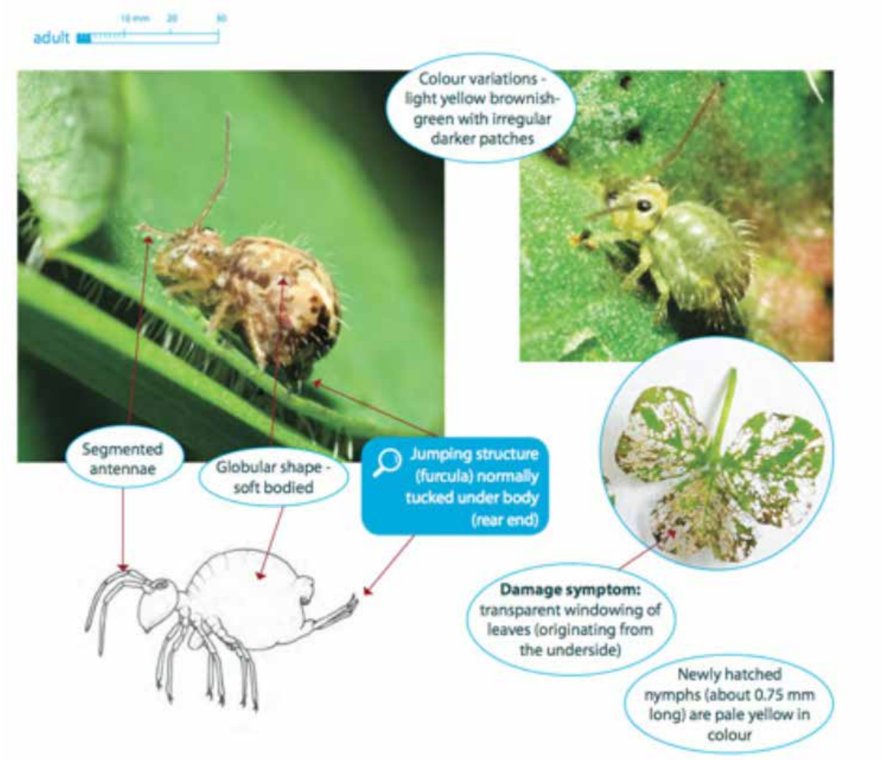

Figure 21: *Distinguishing characteristics of the Lucerne flea.*

Source: Bellati et al. (2012) in cesar

Damage caused by Lucerne flea

Although grasses and cereals are non-preferred hosts, lucerne flea can also cause damage to ryegrass, wheat and barley crops. In pastures, lucerne fleas have a preference for subterranean clover and lucerne.

Lucerne fleas move up plants from ground level, eating tissue from the underside of foliage. They consume the succulent green cells of leaves through a rasping process, avoiding the more fibrous veins and leaving behind a layer of leaf membrane. This makes the characteristic small, clean holes in leaves that can appear as numerous small "windows". In severe infestations this damage can stunt or kill plant seedlings.

Managing Lucerne flea

Monitoring is the key to reducing the impact of lucerne flea. Crops and pastures grown in areas where lucerne flea has previously been a problem should be regularly monitored for damage from autumn through to spring. Susceptible crops and pastures should also be carefully inspected for the presence of lucerne fleas and evidence of damage.

It is important to frequently inspect winter crops, 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 (e.g. omethoate). In areas where damage is likely, a border spray may be sufficient to stop invasion from neighbouring pastures or crops. In many cases spot spraying, rather than blanket spraying, may be all that is required.

If the damage warrants control, treat the infested area with a registered chemical approximately three weeks after lucerne fleas have been observed on a newly emerged crop. This will allow for the further hatch of over-summering eggs but will be before the lucerne fleas reach maturity and begin to lay winter eggs.

In pastures, a follow-up spray may be needed roughly four weeks after the first spray to control subsequent hatches, and to kill new insects before they lay more eggs. Grazing the pasture before spraying will help open up the canopy to ensure adequate spray coverage. The second spray is unlikely to be needed if few lucerne fleas are observed at that time.

Crops are most likely to suffer damage where they follow a weedy crop or a pasture in which lucerne flea has not been controlled. As such, lucerne flea control in the season prior to the sowing of susceptible crops is recommended.

Caution is advised when selecting an insecticide. Several chemicals registered for redlegged earth mites (i.e. synthetic pyrethroids such as cypermethrin) are known to be ineffective against lucerne flea. When both lucerne fleas and redlegged earth mites are present, it is recommended that control strategies consider both pests, and a product registered for both is used at the highest directed rate between the two to ensure effective control.

Information on the registration status, rates of application and warnings related to withholding periods, OH&S, residues and off-target effects should be obtained before making decisions on which insecticide to use. This information is available from the DPI Chemical Standards Branch, chemical resellers, APVMA and the pesticide manufacturer. Always consult the label and MSDS before using any insecticide.

Biological and cultural control

Several predatory mites, various ground beetles and spiders prey upon lucerne fleas. Snout mites (which have orange bodies and legs) are particularly effective predators of this pest (Photo 8). The pasture snout mite (*Bdellodes lapidaria*) and the spiny snout mite (*Neomulgus capillatus*), have been the focus of biological control efforts against lucerne flea.

The pasture snout mite was originally found in WA but has since been distributed to eastern Australia and there are some examples of this mite successfully reducing lucerne flea numbers. Although more rare, the spiny snout mite can also drastically reduce lucerne flea populations, particularly in autumn.

Photo 8: *Predatory adult snout mite.*

Photo: A Weeks. Source: cesar

Appropriate grazing management can reduce lucerne flea populations to below damaging thresholds. This may be because shorter pasture lowers the relative humidity, which increases insect mortality and limits food resources.

Broad-leaved weeds can provide alternative food sources, particularly for juvenile stages. Clean fallowing and the control of weeds within crops and around pasture perimeters, especially of capeweed, can therefore help reduce lucerne flea numbers.

Other cultural techniques such as cultivation, trap and border crops, and mixed cropping can help reduce overall infestation levels to below economically damaging levels, particularly when employed in conjunction with other measures. Grasses are less favourable to the lucerne flea and as such can be useful for crop borders and pastures.

In pastures, avoid clover varieties that are more susceptible to lucerne flea damage, and avoid planting susceptible crops such as canola and lucerne into paddocks with a history of lucerne flea damage. [26]

7.7 Cutworm

Cutworms are caterpillars of several species of night-flying moths, one of which is the well-known bogong moth. The mature grubs are plump, smooth caterpillars (Photo 9). The caterpillars are called cutworms because they cut down young plants as they feed on stems at or below the soil surface. They are most damaging when caterpillars transfer from summer and autumn weeds onto newly emerged seedlings. Natural predators and early control of summer and autumn weeds will help reduce larval survival prior to crop emergence. If required, cutworms can be controlled with insecticides; spot spraying may provide adequate control.

26 G McDonald (2008) Lucerne flea, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/lucerne-flea

Photo 9: *Cutworm larva in typical curled position when disturbed.*

Source: cesar

Cutworms are sporadic pests that are widely distributed in SA, Tasmania, Victoria, WA, NSW and Queensland. Winter generation moths emerge in late spring and summer. Eggs are laid onto summer and autumn weeds, where larvae can then emerge onto newly sown crops.

There are several species of pest cutworms that are all similar in appearance. Generally, larvae of all species grow to about 40–50 mm long and are relatively hairless, with a distinctly plump, greasy appearance and dark head (Figure 22).

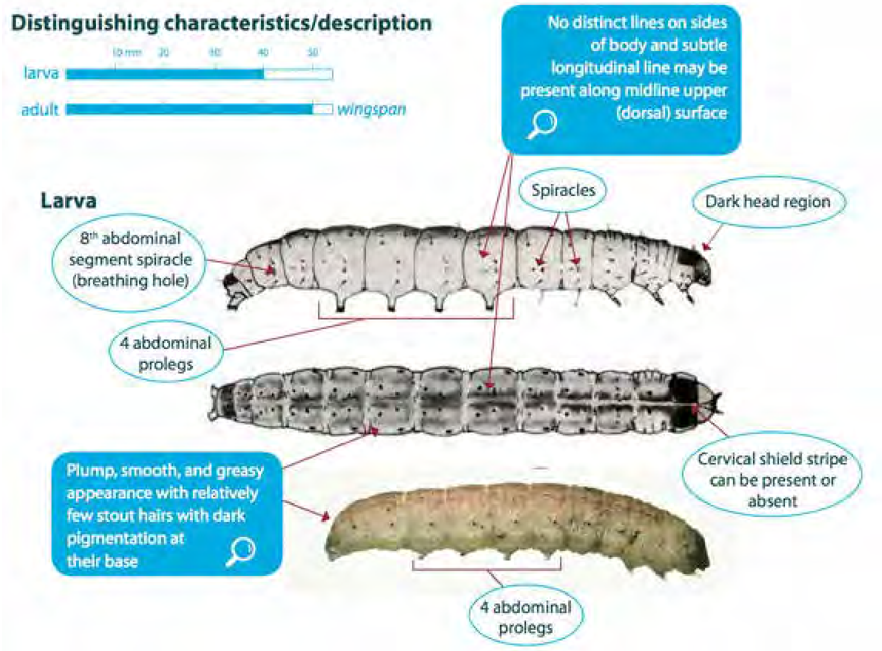

Figure 22: *Distinguishing characteristics of the cutworm.*

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 23). 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.

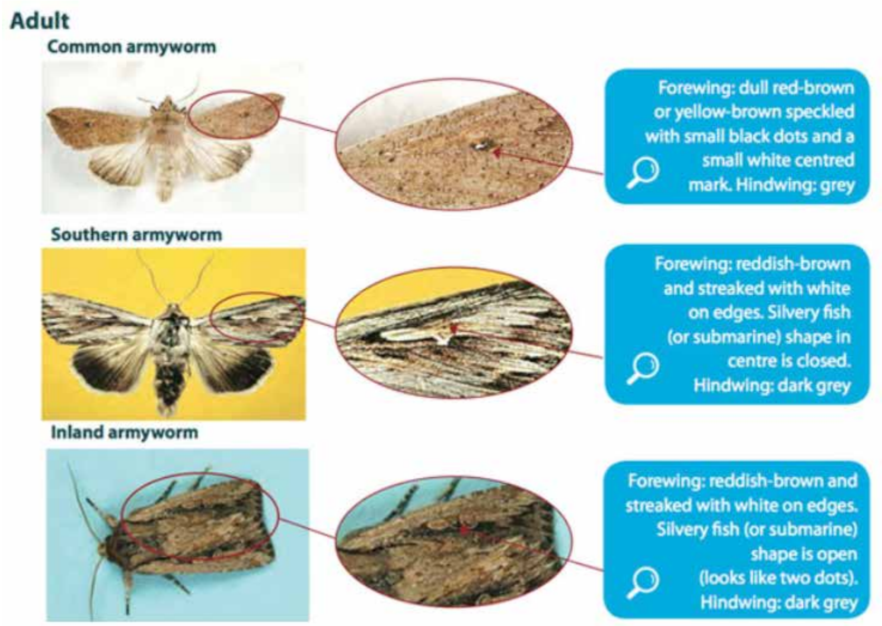

Figure 23: *Distinguishing characteristics of the adult forms of the pink, black and common cutworm.*

Source: Bellati et al. (2012) in cesar

7.7.1 Damage caused by cutworms

Larvae feed at ground level, chewing through leaves and stems. Stems are often cut off at the base, hence the name “cutworm”. Winter crops are most susceptible in autumn and winter, although damage can occur throughout the year, especially in irrigated crops. Damage mostly occurs at night when larvae are active. When numbers of larvae are high, crops can be severely thinned (Photo 10). Smaller larvae can cause similar damage to lucerne flea when they feed on leaf surface tissue. Young plants are favoured and are more adversely affected than older plants.

Occasionally, another undescribed genus of caterpillars marked with a herringbone pattern on their abdomen inflict cutworm-like damage on emerging crops.

Photo 10: *Pink cutworm damage to the plant and paddock.*

Source: cesar

7.7.2 Thresholds for control

Treatment of cereals and canola is warranted if there are two or more larvae per 0.5 m of row.

7.7.3 Managing cutworm

It is important to know the critical periods for cutworm management (Figure 24).

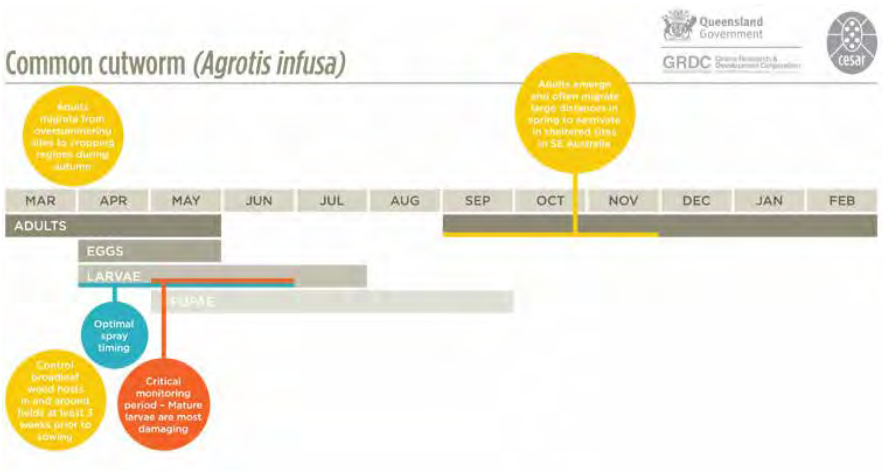

Figure 24: *Critical periods for controlling cutworm.*

Source: cesar

Biological

Naturally occurring insect fungal diseases that affect cutworms can reduce populations. Wasp and fly parasitoids, including the orange caterpillar parasite (*Netelia producta*), the two-toned caterpillar parasite (*Heteropelma scaposum*) and the orchid dupe (*Lissopimpla excelsa*) can suppress cutworm populations. Spiders are generalist predators so will also prey upon cutworms.

Cultural

As autumn cutworm populations may be initiated on crop weeds or volunteers in and around the crop, removal of this green bridge 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]

7.8 Armyworm

Armyworms are caterpillar pests of grass pastures and cereal crops. They are the only caterpillars that growers are likely to encounter in cereal crops, although occasionally native budworm will attack grain when underlying weed hosts dry out. Armyworms mostly feed on leaves, but under certain circumstances will feed on the seed stem, resulting in head loss. The change in feeding habit is caused by depletion of green leaf material or crowding. In the unusual event of extreme food depletion and crowding, they will "march" out of crops and pastures in search of food, which gives them the name "armyworm".

There are three common species of armyworm found in southern Australia:

- Common armyworm (*Mythimna convecta*)
- Southern armyworm (*Persectania ewingii*)
- Inland armyworm (*Persectania dyscrita*)

These are native pests. Common armyworm (*Leucania convecta*) is found in all states of Australia and potentially will invade all major broadacre-cropping regions year round, but particularly in spring and summer. The *Persectania* species are more typically found in southern regions of Australian autumn and winter, but their activity can sometimes extend into spring.

Caterpillars of the three species are similar in appearance. They grow from about 2–40 mm in length. They have three prominent white or cream stripes running down the back and sides of their bodies. These are most obvious where they start on the thoracic segment ("collar") immediately behind the head, and become particularly apparent in larvae that are >10 mm. They have no obvious hairs, are smooth to touch and curl up when disturbed. Armyworms have four abdominal prolegs (Figure 25).

Mature caterpillars are 30–40 mm long. For an accurate identification, they must be reared through to the adult (moth) stage.

Armyworms can be distinguished from other caterpillar pests that may be found in the same place by three pale stripes running the length of the body; these stay constant no matter the variation in the colour of the body.

Other species of caterpillar that may be confused with armyworms include:

27 S Hangartner, G McDonald, P Umina (2015) Cutworm, http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cutworm

Loopers (tobacco looper or brown pasture looper) walk with a distinct looping action and have 1 or 2 pairs of abdominal prolegs. Armyworms have 4 pairs, and when >10 mm do not walk with a looping action.

Budworm larvae have prominent but sparse hairs and bumps on their skin; anthelid larvae are covered in hairs. Armyworms are smooth bodied with no obvious hairs.

Cabbage moth larvae wriggle vigorously when disturbed. Armyworms curl up into a tight "C".

Cutworm (brown or common cutworm) larvae have no obvious stripes or markings and are uniformly brown, pink or black.

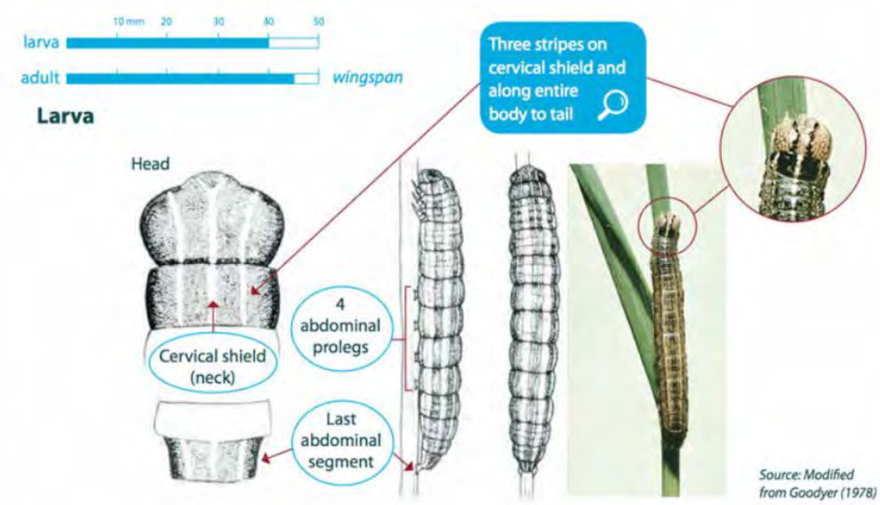

Figure 25: *Distinguishing characteristics of Armyworm larvae.*

Source: cesar

Adults

Moths are often seen flying on warm, humid nights. They are medium-sized, with a wingspan of 30–40 mm. Each species has a characteristic colour and wing markings.

Southern armyworm: grey-brown to red-brown forewings with white zigzag markings on the outer tips and a pointed white "dagger" in the middle of the forewing. The hind wings are dark grey (Figure 26).

Inland armyworm: similar to the southern armyworm except that the white "dagger" in the centre of the forewing is divided into two discrete light ellipses which almost touch. The hind wings are pale grey.

Common armyworm: the forewings are dull yellow to red-brown, speckled with tiny black dots and a small white dot near the centre.

Pupae of all three species are about 20 mm long, shiny brown and are found under clods or within cracks in the soil. [28]

28 G McDonald (1995) Armyworms, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms

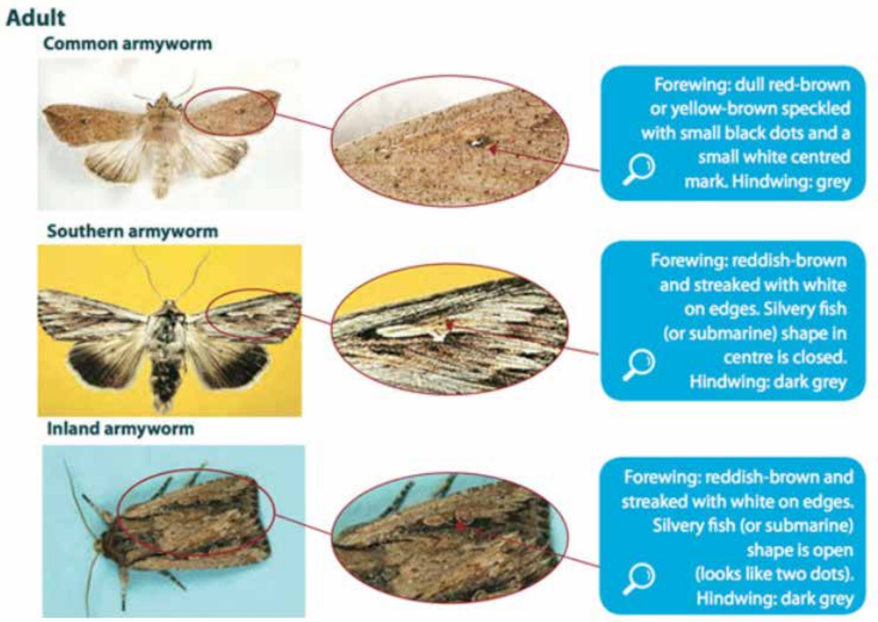

Figure 26: *Distinguishing characteristics of the three Armyworm adult moth species.*

Source: cesar

7.8.1 Damage caused by armyworms

- Prefer lush growth that provides good cover and protection.
- Feed on leaf tissue—leaf margins have tattered/chewed/scalloped appearance; in extreme cases whole leaves may be severed at the stem.
- Caterpillars produce green/straw coloured droppings (size of match head). These are visible between the rows.
- Bare patches adjacent to barley fields or damage to weeds may indicate armyworm presence before it is evident in crops. [29]

The young larvae feed initially from the leaf surface of pasture grasses and cereals. As the winter and spring progress and the larvae grow, they chew “scallop” marks from the leaf edges. This becomes increasingly evident by mid to late winter. By the end of winter or early spring, the larvae are reaching full growth and maximum food consumption. It is this stage that farmers most frequently notice as complete leaves and tillers may be consumed or removed from the plant.

Damaging infestations or outbreaks occur in three situations:

In winter when young tillering cereals are attacked and can be completely defoliated. The caterpillars may come from:

- the standing stubble from the previous year's cereal crop, in which the eggs are laid; or
- neighbouring pastures that dry out, resulting in the resident armyworms being forced to march into the crop.

In spring / early summer when crops commence ripening and seed heads may be lopped.

In early summer when grass pastures are cut for hay, particularly in Gippsland.

Leaves of cereal plants or grasses appear chewed ("leaf scalloping") along the edges. The most damage, however, is caused in ripening crops when the foliage dries off. The armyworms then begin to eat any green areas remaining. In cereals, the last section of the stem to dry out is usually just below the seed head. Armyworms,

29 IPM Guidelines (2016) Armyworm, http://ipmguidelinesforgrains.com.au/pests/armyworm/

MORE INFORMATION

Armyworms—Agriculture Victoria.

particularly the older ones, that chew at this vulnerable spot cause lopping of the heads and can devastate a crop nearing maturity in one or two nights. Generally, the larger the armyworm, the greater the damage. In wheat and barley, whole heads are severed, while in oats individual grains are bitten off below the glumes.

The crops affected include all Gramineae crops including cereals, grassy pastures, corn and maize.

7.8.2 Thresholds for control

Economic threshold estimated at 10 grubs/m^2 (higher than barley because heads are rarely lopped). [30]

For winter outbreaks (during tillering), economic thresholds of 8– 10 larvae/m^2 provide a guide for spray decisions. For spring outbreaks (during crop ripening) spraying is recommended when the density of larvae exceeds 1–3 larvae/m^2 although this figure must be interpreted in the light of:

- timing of harvest;
- green matter available in the crop;
- expected return on the crop; and
- larval development stage (if most are greater than 35–40 mm or pupating, it may not be worth spraying). [31]

7.8.3 Managing armyworms

Sampling and detection

Signs of the presence of armyworms include:

- Chewing/leaf scalloping along the leaf margins.
- Caterpillar excreta or 'frass' which collects on leaves or at the base of the plant. These appear as green or yellow cylindrical pellets 1–2 mm long.
- Cereal heads or oat grains on the ground. Oat grains may be attached to a small piece of stalk (1–2 mm), whereas wind removed grains are not. Barley heads may be severed completely, or hang from the plant by a small piece of stalk.

Early detection is essential, particularly when cereals and pasture seed or hay crops are at the late ripening stage. Although accurate estimates of caterpillar densities require considerable effort, the cost saving is worthwhile.

Sampling can be achieved by using a sweep-net/bucket, or visually ground or crop searching for either caterpillars or damage symptoms.

The sweep-net/bucket method provides a rapid and approximate estimate of infestation size. The net or bucket should be swept across the crop in 180o arcs several times—preferably 100 times—at different sites within the crop to give an indication of density and spread. Armyworms are most active at night, so sweeping will be most effective at dusk. Average catches of more than 5—10 per 100 sweeps suggest that further searches on the ground are warranted to determine approximate densities.

When ground sampling, it is necessary to do at least ten "spot checks" in the crop, counting the number of caterpillars within a square metre.

Most farmers fail to detect armyworms until the larvae are almost fully grown, and 10–20% damage may result. The earlier the detection, the less the damage. The young larvae (up to 8 mm) cause very little damage, and are more difficult to find. The critical time to look for armyworms is the last 3–4 weeks before harvest. [32]

It is important to know the critical periods for control in armyworms (Figure 27).

30 IPM Guidelines (2016) Armyworm, http://ipmguidelinesforgrains.com.au/pests/armyworm/

31 G McDonald (1995) Armyworms, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms

32 G McDonald (1995) Armyworms, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/armyworms

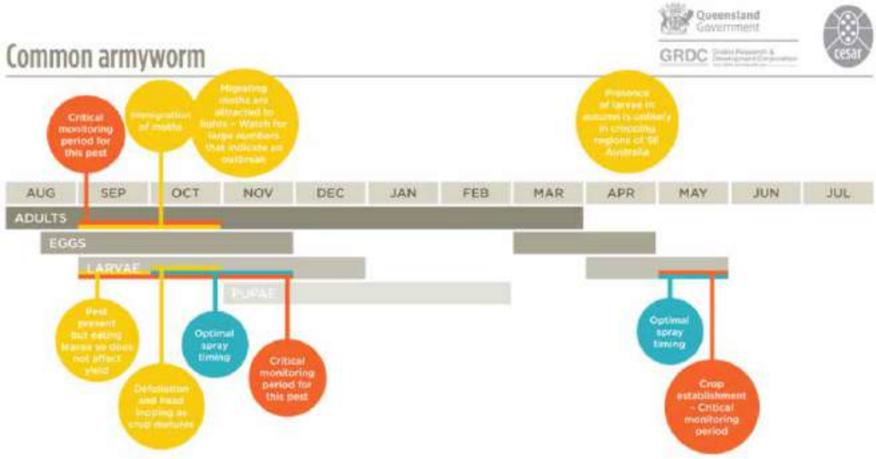

Figure 27: *Critical periods for control in armyworms.*

Source: cesar

Biological control

Around 20 species of predator and parasitoids have been recorded attacking armyworm. The most frequently observed predators are predatory shield bugs, ladybeetles, carabid beetles, lacewings and common brown earwigs. Parasitoids include tachnid flies and a number of wasp species (e.g. *Netelia*, *Lissopimpla*, *Campoletis*). Viral and fungal diseases are recorded as causing mortality of armyworm. Such outbreaks are more common at high armyworm densities.

Cultural control

Control weeds to remove alternative hosts. Armyworm often feed on ryegrass before moving into cereal crops.

Standing stubble from previous crops, dead leaves on crops and grassy weeds are suitable sites for female armyworm to lay eggs.

Larvae can move into cereals if adjacent pastures are chemically fallowed, spray topped or cultivated in spring. Monitor for at least a week post treatment. Damage is generally confined to crop margins.

Chemical control

Effectiveness requires good coverage to get contact with the caterpillars. Control is more difficult in high-yielding crops with thick canopies where larvae are resting under leaf litter at the base of plants.

Armyworms are active at night—spray late afternoon or early evening to maximum likelihood of contact.

Be aware of withholding periods when chemical control is used close to harvest. [33]

7.9 Slugs and snails

Slugs and snails are predominantly pests in the southern and western regions (Table 4). Snails are not a problem in the northern region, however damaging slug populations have been reported in seedling crops in northern NSW and southern Queensland in recent years.

Increased slug and snail activity may be due to the increase in zero/minimum till and stubble retention practices because the organic content of paddocks increases under such systems, providing an increased food source especially to young slugs and snails.

33 IPM Guidelines (2016) Armyworm, http://ipmguidelinesforgrains.com.au/pests/armyworm/

Other risk factors include prolonged wet weather, trash blankets, weedy fallows and a previous history of slugs and snails. Slugs and snails are best controlled before the crop is planted.

Table 4: *Description of common slugs and snails.*

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Slugs				
Grey field or reticulated slug *Deroceras reticulatum*  Photo: Michael Nash, SARDI	Light grey to fawn with dark brown mottling 35–50 mm long Produces a white mucus.	Rasping of leaves. (Complete areas of crop may be missing.)	Autumn to spring when conditions are moist, especially when soil moisture 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
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

Species	Distinguishing features	Characteristic damage	Seasonal occurrence	Other characteristics
Snails				
Vineyard or common white snail *Cernuella virgata*  Photo: Michael Nash, SARDI	Coiled white shell with or without a brown band around the spiral Mature shell diameter 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.
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

7.9.1 Managing slugs and snails

Table 5 provides recommendations for the control of slugs in seedling crops.

Table 5: *Controlling slugs.*

Objectives	Pre-sowing	Germination – Vegetative
Find insects and damage Species of slugs	High risk: • High rainfall areas >450 mm/annum. • Above average spring–autumn rainfall. • Cold wet establishment conditions. • No till stubble retained. • Summer volunteers. • Previous paddock history of slugs. • Soils high in clay and organic matter. • Slugs are nocturnal and shelter during dry conditions and generally not visible.	Damage: • Rasping of leaves. • Leaves have a shredded appearance. • Complete areas of crop may be missing. • Slugs will eat all plant parts but the seedling stage is most vulnerable and this is when major economic losses can occur. • Grey and brown field slugs are mainly surface active but the black keeled slug burrows and can feed directly on germinating seed.
Monitor and record	Monitor with surface refuges to provide an estimate of active density. Refuges can include: • terracotta paving tiles • carpet squares or similar Use a 300 mm by 300 mm refuge when soil moisture is favourable (> 20%) as slugs require moisture to travel across the soil surface. Research has shown that slugs are attracted to the refuges from approximately 1 m hence numbers found can be used as numbers per m^2. Place refuges in areas of previous damage, after rainfall, on damp soil before sowing. Use 10 refuges per 10 hectares. Check the refuges early in the morning, as slugs seek shelter in the soil as it gets warmer. An alternative option to monitoring with refuges is to put out metaldehyde bait strips and check the following morning for dead slugs.	Monitor for plant damage. Slug populations are not even distributed in the field and are often clumped. Where crop damage is evident—inspect the area at night.
Natural enemies	Some species of carabid beetles can reduce slug populations but generally not below established economic thresholds. Free living nematodes that carry associated bacteria that cause slug death are thought to help reduce populations under certain field conditions. Many other soil fauna, such as are protozoa, may cause high levels of slug egg mortality under moist warm conditions however biological controls alone can not be solely relied on for slug control.	
Cultural control	Hard grazing of stubbles. Burning. Cultivation leaving a fine consolidated tilth. Removal of summer volunteers. Rolling at sowing. Early sowing for quick establishment of canola.	

Objectives	Pre-sowing	Germination – Vegetative
Thresholds	Thresholds have been established but should be used as a guide only. Also, take into account the field, the season, crop health and weather conditions.	Suggested thresholds per square metre: • Grey field slug • Canola 0.5–1.5 • Cereals 5–15 • Pulses 1–2 • Black keeled slug • Canola <1 • Cereals 1–2 • Pulses 1–2
Chemical control	Baiting slugs is the only chemical option available to manage slugs. Molluscidial baits containing either metaldehyde or chelated iron are IPM compatible. Baits containing methiocarb are also toxic to carabid beetles—one of the few predators of slugs. Different responses to bait can be due to species behaviour. The value of applying bait after a significant rainfall event prior to sowing is still to be tested. For black keeled slugs—broadcast baits when dry or place with seed at sowing. For grey field slugs—broadcast baits Do not underestimate slug populations—always use rate that gives 25–30 per metre. Calibrate bait spreaders to ensure width of spread, evenness of distribution and correct rate.	Bait after/at sowing prior to crop emergence when soil is moist (i.e. >20% soil moisture). Re-apply baits to problem areas 3–4 weeks after first application if monitoring indicates slugs are still active. The number of baits/ha is more important than the total weight of bait/ha. Current research indicates that 250,000 bait points/ha is the minimum required for effective control.
Multi-pest interactions	Different species respond differently to environmental and field conditions leading to staggered emergence and need for repeated application under some conditions.	
Communicate and discuss management	Know paddock history and slug presence before sowing. Where retained stubble—graze or burn to control slugs before sowing. Control summer volunteers that may harbour slugs. Discuss optimum times for baiting and observations regarding population activity. Consult industry publications for up-to-date information of pest problems. No single method will provide complete control of slugs. Consider cultural and chemical control and work on pest control year-round to achieve a reasonable level of control.	

Source: IPM Guidelines

MORE INFORMATION

Slug management Factsheet.

Table 6 provides recommendations for the control of snails in seedling crops.

Table 6: *Controlling snails.*

Objectives	Pre-sowing	Seedling – Vegetative	Grain fill / Podding	Harvest
Find insects and damage Species of snails	High risk: • Weedy fields • Alkaline calcareous soils • Retained stubble • Wet spring, summer, autumn History of snails All species of snails congregate at the base of summer weeds or in topsoil. Pointed snail species can also be found at the base or up in stubble as well as inside stubble stems. Snails appear to build up most rapidly in canola, field peas and beans but can feed and multiply in all crops and pastures. Snails are most active after rain and when conditions are cool and moist. Snails are dormant in late spring and summer.	Damage: • Snails consume cotyledons and this may resemble crop failure • Shredded leaves where populations are high. • Chewed leaf margins • Irregular holes A wide range of snail sizes are an indication of snails breeding in the area. If most snails are the same size, snails are moving in from other areas. Round snails favour resting places off the ground on stubble, vegetation and fence posts. Pointed snails are found on the ground in shady places.	Snails can be found up in the crop prior to harvest. Check for snails under weeds or shake mature crops unto tarps	Snails are predominantly a grain contaminant. At harvest, snails move up in the crop and may shelter between grains or under leaves. They can also be found in windrows. The small pointed snail is especially hard to screen from canola grain due to similar size. Buyers will reject grain if: • More than half a dead or one live snail is found in 0.5 litre of wheat. • More than half a dead or one live snail is found in 200 gram pulse sample.
Monitor and record	Monitor snails regularly to establish their numbers, types and activity and success of controls Look for snails early morning or in the evening when conditions are cooler and snails are more active. Key times to monitor: • 3–4 weeks before harvest to assess need for harvester modifications and cleaning • After summer rains—check if snails are moving from resting sites • Summer to pre-seeding—check numbers in stubble before and after rolling/slashing/cabling Monitoring technique: • Sample 30 x 30 cm quadrat at 50 locations across the paddock. • If two snail groups are present (round and conical), record the number of each group separately. • To determine the age class of round snails, place into a 7 mm sieve box, shake gently and they will separate into two sizes: >7 mm (adults) and <7 mm (juveniles). • Sieve boxes can be constructed from two stackable containers, e.g. sandwich boxes. Remove the bottom from one and replace by a punch hole screen. Suggested screen size is 7 mm round or hexagonal. • Five sampling transects should be taken in each paddock. One transect is taken at 90° to each fence line whilst the fifth transect runs across the centre of the paddock. • Take five samples (counts) 10 m apart along each transect. • Record the size and number of the snails in each sample. Average the counts for each transect and multiple this figure by 10 to calculate the number of snails per m^2 in that area of the paddock.			
Natural enemies	Free living nematodes when carrying associated bacteria that causes snail death are thought to help reduce populations under certain field conditions.			

Objectives	Pre-sowing	Seedling – Vegetative	Grain fill / Podding	Harvest
Cultural control	Hard grazing of stubbles Cabling and/or rolling of stubbles—when soil temperature is above 35°. Burning—if numbers are very high and ensure hot, even burns. Cultivation leaving a fine consolidated tilth. Removal of summer weeds and volunteers.			Reduce contamination. Stripper fronts in medium to heavy crops. Raising cutting heights. Harvester modifications Seed cleaning Windrowing. Trials with windrowed barley resulted in reduced round snail contamination. Early windrowing when cool produces better results.
Thresholds	To control snails, apply a combination of treatments throughout the year.	Thresholds can be unreliable due to the interaction between weather, crop growth and snail activity. For example: high snail populations in the spring do not always relate to the number of snails harvested. Their movement into the crop canopy is dictated by weather conditions prior to harvest. Suggested thresholds for round snails: • Cereals—20/m^2 • Pulses and oilseeds—5/m^2 • Suggested thresholds for small pointed snails: • Cereals—40/m^2 • Oilseeds—20/m^2 • Baiting before egg lay is vital.		Thresholds to warrant harvester modifications are difficult to define. Contamination depends on snail types and size in relation to grain as well the position of snails in relation to cutting height.
Chemical control	Molluscidial baits containing either Metaldehyde or Chelated iron are IPM compatible. Apply to the bare soil surface when snails are active after autumn rain as early as March. Aim to control snails pre-season.	Mature snails larger than 7 mm in length or diameter will feed on bait but this can be less effective on juveniles. Baiting before egg lay is vital. Bait when snails are moving from resting sites after summer rains. Stop baiting 8 weeks before harvest to avoid bait contamination in grain. Bait rates need to be at the highest label rate to achieve a greater number of bait points. The actual number is yet to be determined; hence, label rates may be revised ion the future. Note that in cool, moist conditions, snails can move 30 m/week and treated fields can be re-invaded from fence lines, vegetation and roadsides.		Rain at harvest can cause snails to crawl down from crops.
Multi-pest interactions	Baits containing Methiocarb are toxic to a range of other invertebrates and beneficials.			

Objectives	Pre-sowing	Seedling – Vegetative	Grain fill / Podding	Harvest
Communicate and discuss management	Know paddock history and snail presence before sowing.			
	Where retained stubble—graze, burn or bash to remove snails before sowing.			
	Control summer volunteers and brassica weeds that may harbour snails.			
	Consider harvester modifications id snails present at harvest.			
	Discuss optimum times for baiting.			
	Consult industry publications for up-to-date information of pest problems.			

Source IPM Guidelines

7.10 Wireworms and False wireworms

Wireworms and false wireworms are common, soil-inhabiting pests of newly sown winter and summer crops. Wireworms are the larvae of several species of Australian native beetles that are commonly called "click" beetles, coming from the family *Elateridae*.

False wireworms are also the larval form of adult beetles, some of which are known as pie-dish beetles, which belong to another family (*Tenebrionidae*), but have distinctively different forms and behaviour. Both groups inhabit native grassland and improved pastures where they cause little damage. However, cultivation and fallow decimates their food supply, and hence any new seedlings that grow may be attacked and sometimes destroyed. They attack the pre- and post-emerging seedlings of all oilseeds, grain legumes and cereals, particularly in light, draining soils with a high organic content. Fine seedling crops like canola and linola are most susceptible.

The incidence of damage caused by wireworms and false wireworms is increasing with increasing use of minimum tillage and short fallow periods.

7.10.1 False wireworms

(Family *Tenebrionidae*; numerous species)

These insects are the larvae of native beetles that normally live in grasslands or pastures and cause little or no damage in this situation. In crops, they are mostly found in paddocks with high stubble and crop litter contents. They may affect all winter-sown crops.

There are a large and varied number of species, but the general characteristics of false wireworm are as follows.

Larvae are cylindrical, hard bodied, fast moving, golden brown to black-brown or grey with pointed upturned tails or a pair of prominent spines on the last body segment. There are several common groups (genera) of false wireworms found in south-eastern Australia:

- The grey or small false wireworm (*Isopteron (Cestrinus) punctatissimus*). The larvae grow to about 9 mm (3/8") in length. They are grey-green in colour, have two distinct protrusions from the last abdominal (tail) segment and tend to have a glossy or shiny exterior (Figure 28). Hence, they are most easily recognised in the soil on sunny days when their bodies are reflective. The adults are slender, dark brown and grow to about 8 mm in length. The eggs are less than 1 mm in diameter. There are several species of this pest genus, although *I. punctatissimus* appears to be the species most associated with damage.

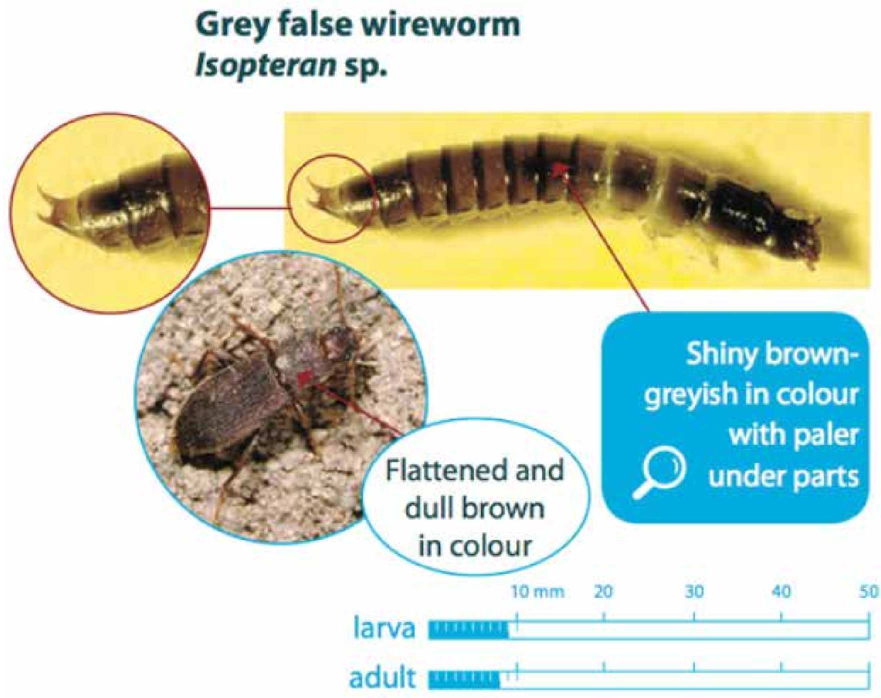

Figure 28: *Distinguishing characteristics of the grey false wireworm.*

Source: cesar

- The large or eastern false wireworm (*Pterohelaeus spp*.). These are the largest group of false wireworms. They are the most conspicuous in the soil and grow up to 50 mm in length. They are light cream to tan in colour, with tan or brown rings around each body segment, giving the appearance of bands around each segment. The last abdominal segment has no obvious protrusions, although, under a microscope, there are a number of distinct hairs. Adults are large, conspicuous and often almost ovoid beetles with a black shiny bodies (Photo 11).

Photo 11: *Eastern false wireworm adult beetle (left) and larva (right).*

Source: cesar

- The southern false wireworm (*Gonocephalum spp*.) grows to about 20 mm in length, and has similar body colours and marking to the large false wireworm. Adults are generally dark brown-grey, oval beetles, which sometimes have a coating of soil on the body (Figure 29). Adults have the edges of the body flanged, hence the common name 'pie-dish' beetles.

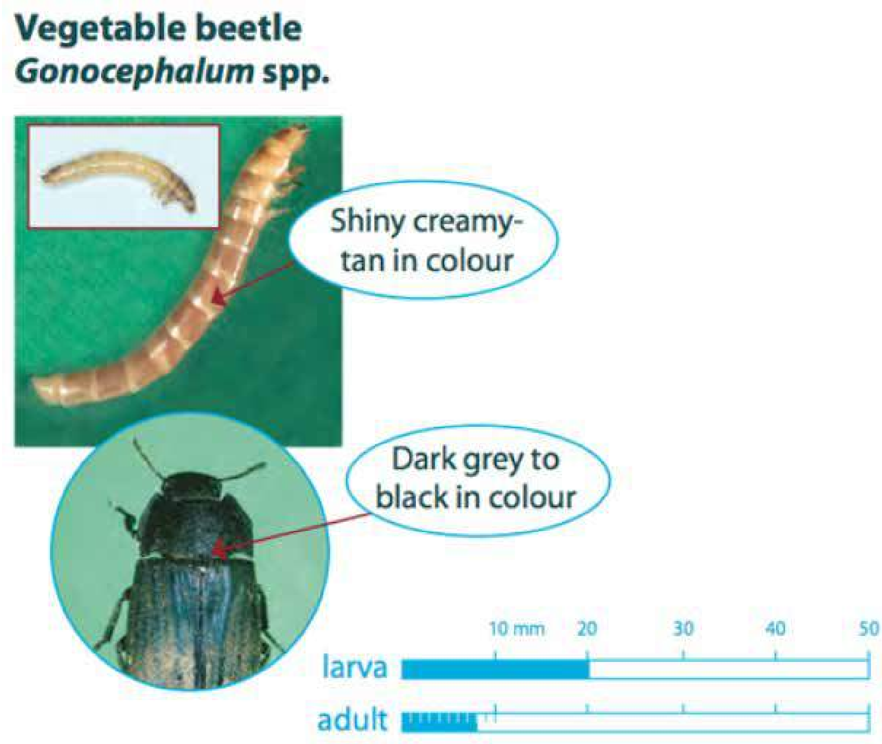

Figure 29: *Distinguishing characteristics of the southern false wireworm.*

Source: cesar

Biology

Usually only one generation occurs each year. However, some species may take up to 10 years to complete the life cycle. Adults emerge from the soil in December and January and lay eggs in or just below the soil surface, mostly in stubbles and crop litter. Hence, larvae are most commonly found in stubble-retained paddocks.

Larvae of most false wireworm species prefer to feed on decaying stubble and soil organic matter. When the soil is reasonably moist, the larvae are likely to aggregate in the top 10–20 mm where the plant litter is amassed. However, when the soil dries, the larvae move down through the soil profile, remaining in or close to the subsoil moisture, and occasionally venturing back to the soil surface to feed. Feeding is often at night when the soil surface becomes dampened by dew.

Nothing is known of the conditions that trigger the switch in the false wireworm feeding from organic matter/litter to plants. Significant damage is, however, likely to be associated with soils that remain dry for extensive periods of time. Larvae are likely to stop feeding on organic matter when it dries out, and when the crop plants provide the most accessible source of moisture.

Damage caused by false wireworms

Affected crops may develop bare patches, which could be large enough to require re-sowing (Photo 12). Damage is usually greatest when crop growth is slow due to cold, wet conditions.

Photo 12: *False wireworm damage to pasture.*

Source: SARDI in cesar

Infestations of the small false wireworm can be as high as hundreds of larvae per square meter, although densities as low as five larger false wireworm larvae/m^2 can cause damage under dry conditions.

The larvae of the small false wireworm are mostly found damaging fine seedling crops shortly after germination. They feed on the hypocotyl (seedling stem) at or just below the soil surface. This causes the stem to be "ring-barked", and eventually the seedling may be lopped off or it wilts under warm conditions. Larger seedlings (e.g. grain legumes) may also be attacked, but the larvae appear to be too small to cause significant seedling damage.

he larger false wireworms can cause damage to most field crops. The larvae can hollow out germinating seed, sever the underground parts of young plants, or attack the above surface hypocotyl or cotyledons. In summer, adult beetles may also chew off young sunflower seedlings at ground level. Damage is most severe in crops sown into dry seedbeds and when germination is slowed by continued dry weather.

7.10.2 True wireworm

(Family *Elaterida*e; numerous species)

These slow moving larvae tend to be less common, although always present, in broadacre cropping regions and are generally associated with wetter soils than that of false wireworms.

Larvae grow to 15–40 mm, are soft-bodied, flattened and slow moving; they can be distinguished from false wireworms, which are hard bodied, cylindrical and fast moving. Their colour ranges from creamy yellow in the most common species to red brown; their head is dark brown and wedge-shaped. The tailpiece is characteristically flattened and has serrated edges. Adults are known as "click" beetles, due to their habit of springing into the air with a loud click when placed on their backs. They are dark brown, elongated and 9–13 mm long (Figure 30).

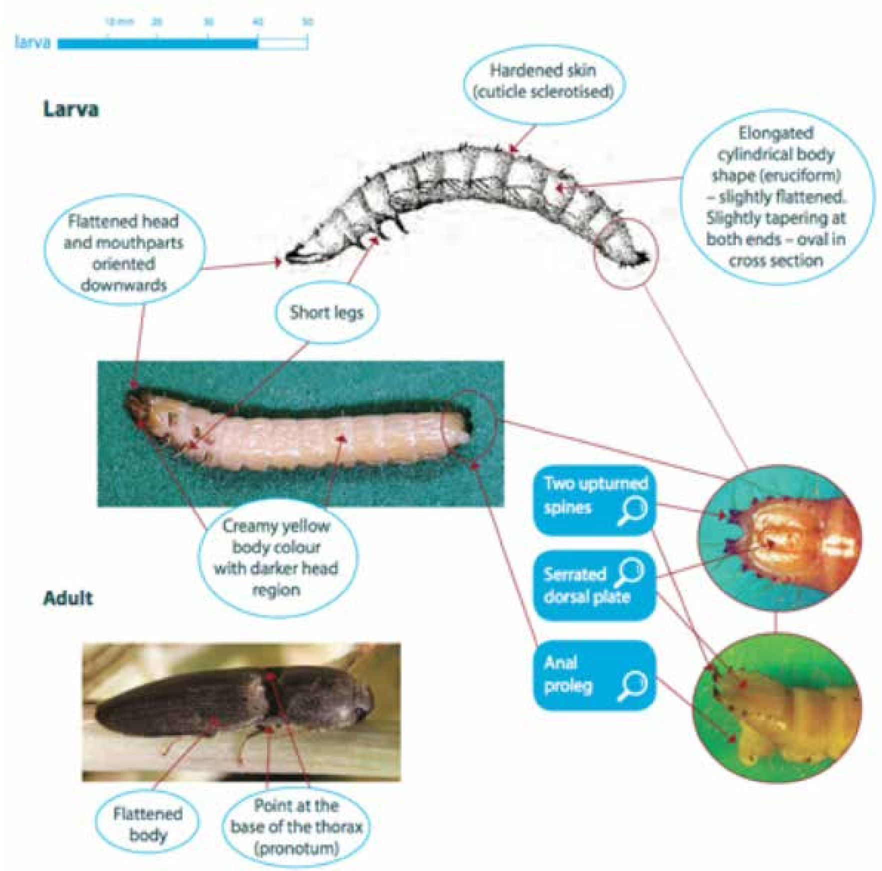

Figure 30: *Distinguishing characteristics of true wireworms.*

Source: cesar

Biology

There may be one or several generations per year, depending on species. Most damage occurs from April to August and adults emerge in spring. Wireworms prefer low-lying, poorly drained paddocks and are less common in dry soils. Larvae are reasonably mobile through the soil and will attack successive seedlings as they emerge. Adults are typically found in summer and autumn in bark, under wood stacks or flying around lights.

There is little known of the biology of most species, but one species (*Hapatesus hirtus*) is better understood. This species is known as the potato wireworm, although it is found in many other crop and pasture situations. It is very long-lived and probably takes five years or more to pass through all the wireworm stages before pupating and finally emerging as an adult beetle.

Adult click beetles emerge in spring and summer, mate and lay eggs, and then may spend a winter sheltering under the bark of trees. The connection between trees and adult beetles is probably why damage is often, but not always, most pronounced on tree-lines. The wireworms have a long life in the soil and are active all year, even in winter.

Damage

The damage caused by wireworms is similar to that of false wireworms, except that most damage is restricted to below the soil surface. Larvae eat the contents of germinating seed, and underground stems of establishing plants, causing wilting and death.

7.10.3 Sampling and detection

The principles for detection and control of false and true wireworms are generally similar, although different species may respond slightly differently according to soil conditions.

Sampling

Crops should be sampled immediately before sowing. There are two methods available, although neither provides a 100% reliable method of detection. This is because larvae change their behaviours according to soil conditions, particularly soil moisture and temperature.

- Soil sampling. Take a minimum of five random samples from the paddock. Each sample should consist of the top 20 mm of a 0.50 m area of soil. Carefully inspect the soil for larvae. Calculate the average density per meter squared by multiplying the average number of larvae found in the samples by 4. Control should be considered if the average exceeds 10 small false wireworms, or 10 of the larger false wireworms.
- Seed baits. Seed baits have been used successfully to sample true and false wireworms in Queensland and overseas. In Victoria, they have not been rigorously tested. Preliminary work has shown that they can be used to show the species of larvae present, and give an approximate indication of density. Take about 200–300 gm of a large seed bait, such as that of any grain legume, and pre-soak over 24 hours. Select 5–10 sites in the paddock and place a handful of the soaked seed into a shallow hole (50 mm), then cover with about 10 mm of soil. Mark each hole with a stake, and re-excavate each hole after about 7 days. Inspect the seed and surrounding soil for false wireworm larvae. This technique is most likely to be successful when there is some moisture within the top 100 mm of soil.

Detection

Larvae of the small false wireworms are relatively difficult, although not impossible, to see in grey and black soils because of their small size and dark colour. However, they can be found in the top 20 mm of dry soil by carefully examining the soil in full sunlight. Larvae of the other false wireworm species are more prominent because of their relatively pale colour and large size.

7.10.4 Control

Crop residues and weedy summer fallows favour survival of larvae and over-summering adult beetles. Clean cultivation over summer will starve adults and larvae by exposing them to hot dry conditions, thus preventing population increases. Suitable crop rotations may also limit increases in population numbers. Seedbeds must be sampled prior to sowing if control is to be successful. Insecticides may be applied to soil or seed at sowing. Most chemicals registered for false wireworm control are seed treatments, although these may not be consistently reliable. They probably work best when the seedling grows rapidly in relatively moist soils. Adults may also be controlled with insecticide incorporated into baits. If damage occurs after sowing, no treatment is available, other than re-sowing bare patches with an insecticide treatment. The critical periods for control of false wireworm are shown in Figure 31 below. [34]

34 G McDonald (1995) Wireworms and false wireworms. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms

MORE INFORMATION

[False wireworms in seedling crops]

[Plague locusts—Identification and biology]

[Australia plague locust commission]

[Australian plague locust response—assessment of effects]

VIDEOS

WATCH: Plague locust videos

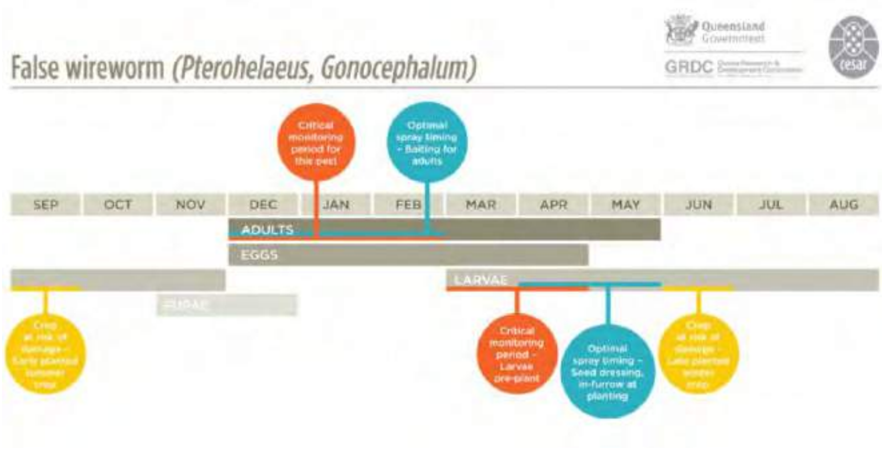

Figure 31: *Critical periods for control in false wireworm.*

Source: cesar

7.11 Plague locusts

Following the major Australian Plague Locust outbreak in southern Australia in 2010 and early 2011, locust numbers returned to near normal levels in most areas.

Landholders should be aware that locusts can have an impact on Victorian and southern Australian agriculture in any given season, but usually on a more localised scale.

The Australian Plague Locust, *Chortoicetes terminifera*, is a native Australian insect (Photo 13). It is a pest of pastures, field crops, and vegetables infrequently in South Australia and Victoria and more commonly in NSW and southern Queensland. [35]

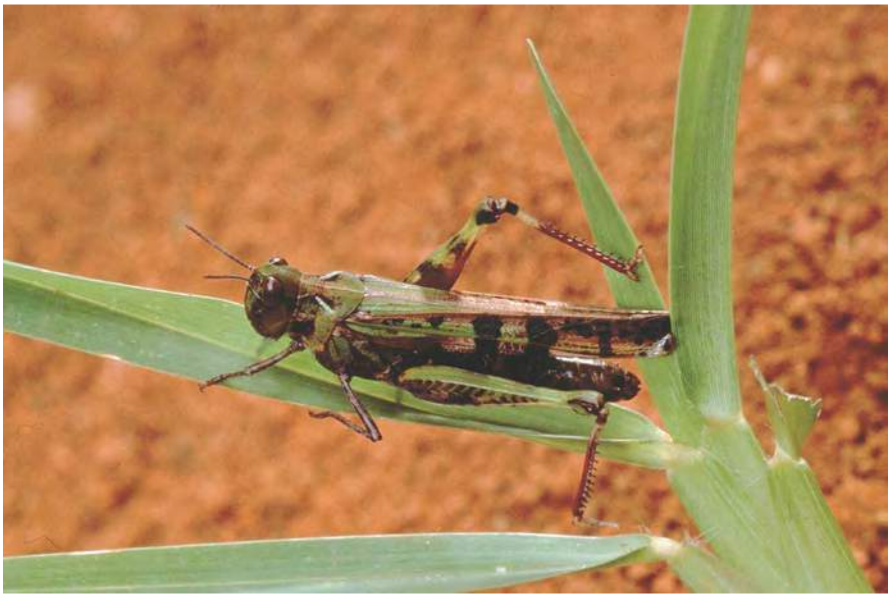

Photo 13: *Australian plague locust on grass leaf.*

Source: DAFWA

35 Agriculture Victoria. Australia Plague locusts: Identification and biology factsheet, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/plague-locusts/fact-sheet-identification-and-biology

Nematode management

Key messages

- Rye is resistant to cereal cyst nematodes and is a poor host to the root lesion nematode (*Pratylenchus neglectus*), providing an alternative management approach for these diseases. [1]
- Rye can reduce the amount of cereal cyst nematodes (CCN) in a paddock. In one study, the biggest reduction in CCN numbers occurred in cereal rye (cv. South Australia), which reduced populations by 92% in the first year. [2]
- Root lesion nematodes (*Pratylenchus thorne*i and *P. neglectus*) cost Australian growers in excess of $250 million/annum.
- At least 20% of cropping paddocks in south-eastern Australia have populations of root lesion nematodes (RLN) high enough to reduce yield. [3]
- Variety choice is critical in managing nematode populations in the soil.
- Soil testing is the best way to diagnose nematode infestations in paddocks and will subsequently inform management decisions.

The most important root and crown diseases of cereal crops in southern Australia are CCN, take-all, rhizoctonia root rot, crown rot and RLN. These diseases can cause significant yield loss in crops. Fortunately, they can be easily controlled with crop rotation and resistant varieties. [4]

Successful management relies on:

- farm hygiene to keep fields free of RLN;
- growing tolerant varieties when RLN are present, to maximise yields; and rotating with resistant crops to keep RLN 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.

Cereal root disease management in Victoria and southern Australia

Take-home messages

- Minimise losses associated with root diseases by inspection of plant roots in the previous crop or by using a PreDicta B soil test prior to sowing to identify at risk paddocks.
- Crown rot will be an important disease if the season finishes with a dry spring, as inoculum levels are high from the previous season. Reduce risk by rotating to non-cereal crops.
- In paddocks with high numbers of RLN, yield losses can be minimised by selecting partially tolerant cultivars and avoiding late sowing. Resistant cultivars can reduce nematode densities and therefore reduce losses in subsequent intolerant crops.
- CCN is a very damaging nematode if numbers are allowed to increase by growing susceptible cereals.

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1 L Martin (2015) Growing Cereal Rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

2 JM Fisher, TW Hancock (1991) Population dynamics of Heterodera avenae Woll. in South Australia. Crop and Pasture Science, 42(1), 53-68.

3 Agriculture Victoria, (2013), Cereal root diseases, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

4 G Hollaway (2013) Cereal root diseases, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

- Rhizoctonia root rot will likely be a low risk if there is a wet summer with multiple rainfall events, provided summer weeds are controlled.
- Take-all will be a low risk if there is a dry spring, limiting inoculum build up.

Cereal root diseases can have serious impacts on grain yield in the absence of adequate control. The key to preventing root diseases is to identify paddocks at risk by inspecting the roots of previous cereal crops or taking a PreDicta B soil test prior to sowing. Knowledge of the potential root diseases in a paddock then enables the most appropriate control strategies to be implemented prior to and/or at sowing. Management must be implemented prior to sowing as there are no in-crop management options available for the control of root diseases, compared with many foliar diseases. [5]

8.1 Root-lesion nematode (RLN)

Key points

- RLN reduce development of lateral roots, which decreases the ability of plants to extract water and nutrients.
- *Pratylenchus neglectus* and *Pratylenchus thornei* are the main RLN causing yield loss in the southern agricultural region of Australia. They often occur together.
- Wheat is the main host, however varieties vary in resistance and tolerance.
- Traditional break crops can also be hosts. Host range varies for each *Pratylenchus* species.
- Yield losses can be reduced by rotation with resistant and tolerant crops and varieties, good nutrition and sowing early.
- Over 90% of paddocks in the Wimmera and Mallee regions have RLN present. [6]

The RLN are a genus of microscopic plant parasitic nematode that are soil-borne, ~0.5 to 0.75 mm in length, and feed and reproduce inside roots of susceptible crops or plants. There are two common species of RLN in the southern region: *Pratylenchus thornei* (*Pt*) and *Pratylenchus neglectus (Pn)*. They often occur together.

At least 20% of cropping paddocks in south-eastern Australia have populations of RLN high enough to reduce yield. [7]

RLN are migratory root endoparasites that are widely distributed in the cereal-growing regions of Australia and can reduce grain yield by up to 50% in many current varieties.

Rye is a poor host to the root lesion nematode (*Pratylenchus neglectus*), providing an alternative management approach for these diseases. [8]

The extent of RLN occurrence across Australia has recently been estimated (Figure 1).

5 G Hollaway, J Fanning, F Henry, A McKay (2015) GRDC Update Papers: Cereal root disease management in Victoria, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Cereal-root-disease-management-in-Victoria

6 CropPro (2014) Root lesion nematode (RLN), http://www.croppro.com.au/crop_disease_manual/ch03s07.php

7 Agriculture Victoria (2013) Cereal root diseases, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

8 L Martin (2015) Growing Cereal Rye to increase carbon and prevent wind erosion. Liebe Group,

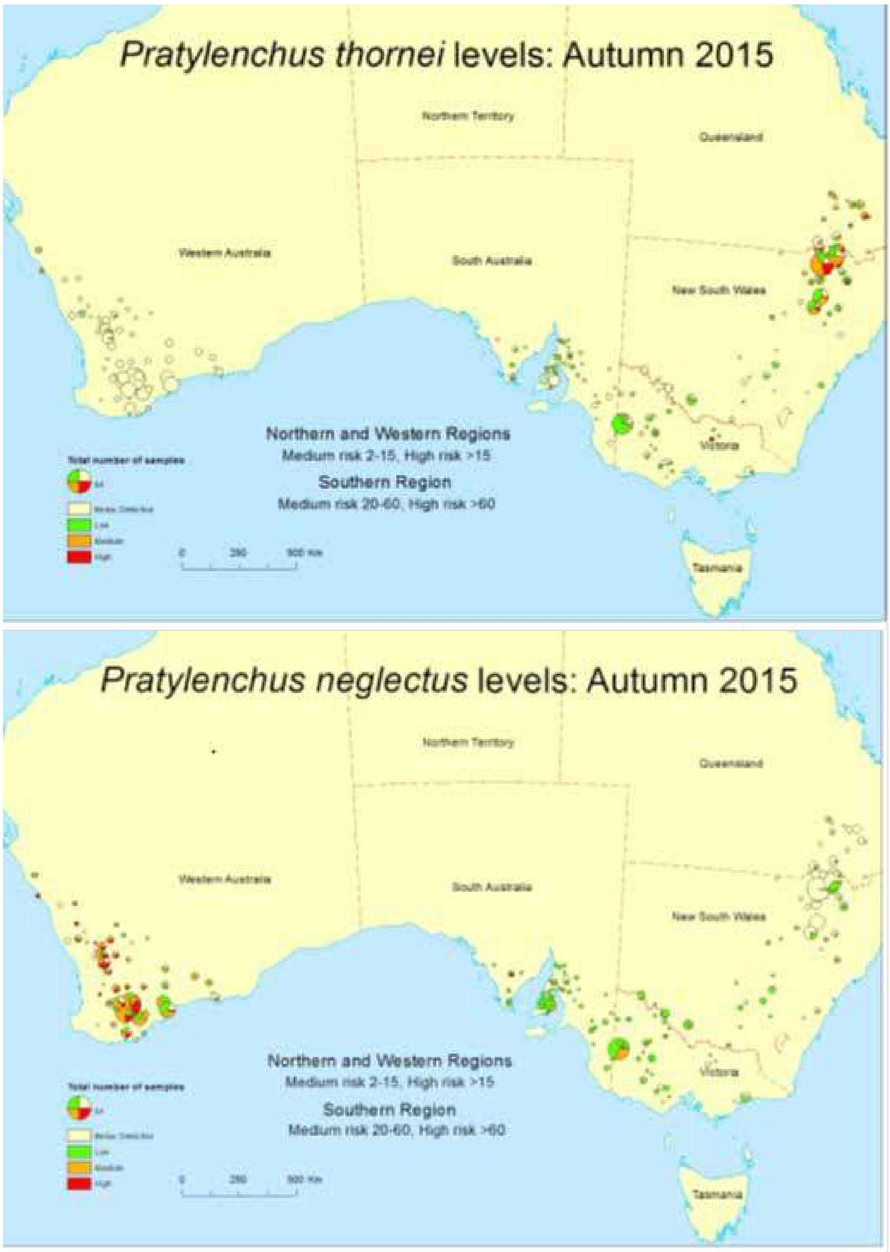


Figure 1: *The distribution and risk of causing yield loss of samples submitted to PreDictaB, SARDI in autumn 2015 for (top)* Pratylenchus thornei *and (bottom)* P. neglectus.

Maps are reproduced with permission from SARDI

Source: GRDC

RLN emerged as potential problems in cereals (and other crops) after management strategies were implemented to control CCN and take-all. Yield losses in the southern region are variable and currently under investigation, but present estimates for intolerant varieties indicate a 1% yield loss per 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.

VIDEOS

WATCH: GCTV6: Root-lesion nematodes.

WATCH: Understanding root-lesion nematodes.

RLN survive summer as dormant individuals in dry soil and roots, and become active after rain. They can survive several wetting/drying cycles. About three generations of the nematodes are produced each season, with the highest multiplication in spring. [9]

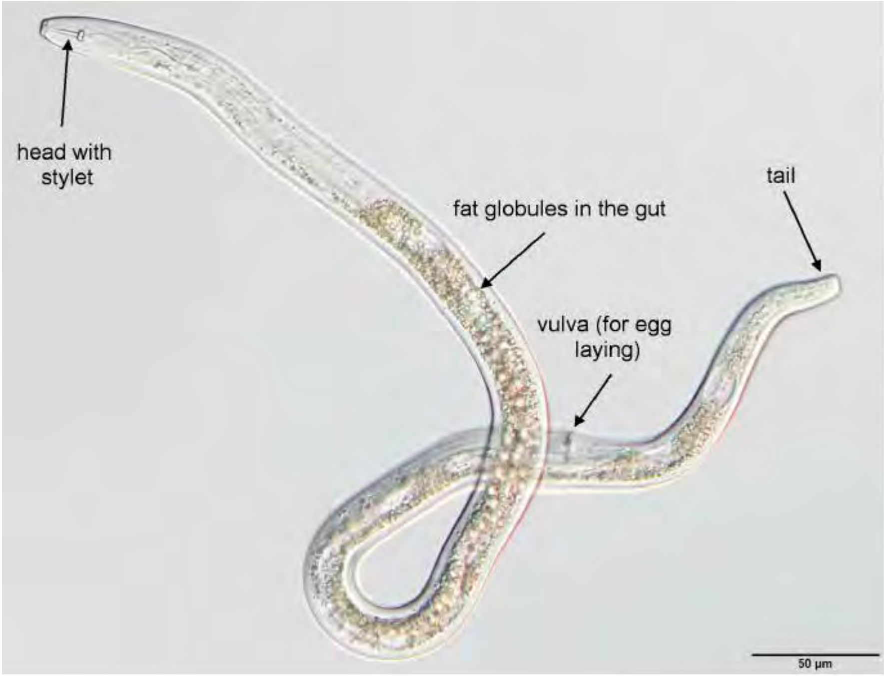


Photo 1: *A* Pratylenchus thornei *adult female viewed under the microscope. The nematode is approximately 0.65 mm long.*

Source: GRDC

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.

9 A McKay (2016) Root lesion nematode—South Australia, http://www.soilquality.org.au/factsheets/root-lesion-nematode-south-australia

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 are 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. [10]
- Unlike the CCN, RLN do not cause the roots to swell or knot and no cysts are produced. [11]

10 DAFWA (2016) Diagnosing Root lesion nematode in cereals, https://agric.wa.gov.au/n/2166

11 CropPro (2014) Root lesion nematode (RLN), http://www.croppro.com.au/crop_disease_manual/ch03s07.php

Photo 3: *Discolouration and lack of lateral roots on cereals is caused by root lesion nematodes.*

Photo: Frank Henry. Source: Soilquality.org

VIDEOS

WATCH: How to diagnose root-lesion nematode.

8.1.2 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 4).

Photo 4: *Sampling for PreDicta B*

Source: GRDC

MORE INFORMATION

GRDC Update Paper: Root-lesion nematodes; importance, impact and management.

VIDEOS

WATCH: Root-Lesion Nematodes. Resistant cereal varieties have surprising impacts on RLN numbers.

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 your risk of yield loss.

SARDI process PreDicta B samples weekly between February and mid-May (prior to crops being sown) every year.

These timeframes help assist growers with cropping programs.

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

8.1.3 Varietal resistance or tolerance

Few cereals are resistant to RLN. It is important to check the resistance ratings of cultivars, as current research is highlighting differences between cultivars. Rye is thought to be resistant to *P. neglectus.* [12]

8.1.4 Damage caused by RLN

RLN are more likely to be a problem when:

- Susceptible varieties are grown sequentially increasing nematode numbers.
- An intolerant crop is sown.
- Sowing is delayed. [13]

During recent years the Department of Economic Development and SARDI have conducted field studies to quantify losses caused by RLN in the southern cropping region. This work measured grain yield in the presence of high and low numbers of the target nematode. Table 1 shows the average yield loss caused by RLN in the five most intolerant cereal cultivars in Victorian field trials. There was large seasonal effects observed. The yield losses caused by *P. neglectus* were less than those caused by *P. thornei*.

Table 1: *Average yield loss due to root lesion nematodes in the five most intolerant cereal cultivars across five growing seasons along with average rainfall.*

	P. thornei **(Banyena)**		***P. neglectus*** **(Dooen)**	
Year	**Yield Loss (%)**	**Rainfall (mm)**	**Yield Loss (%)**	**Rainfall (mm)**
2011	12.2	241	2.0	256
2012	9.9	268	6.7	254
2013	1.9	353	2.5	326
2014	4.3	253	6.7	215

Source: GRDC

12 Soilquality.org. Root lesion nematode Factsheet, http://soilquality.org.au/factsheets/root-lesion-nematode

13 G Hollaway (2013) Cereal root diseases, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

8.1.5 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 following crops can be significantly reduced.

How long does it take to reduce Pt in soils?

Key points

- *P. thornei* (Pt) populations greater than 40,000/kg at harvest will require a double break of around 40 months free of a host to reduce the population below the accepted threshold of 2,000 Pt/kg.
- *P. thornei* populations greater than 10,000/kg at harvest will require a single break of around 30 months free of a host to reduce the population below the accepted threshold of 2,000 Pt/kg
- Weeds can be a host, so fallows must be weed free and free of volunteers.

Cereal cropping trials in the Northern region have highlighted the importance of the initial population when reducing nematode populations below the damage threshold. Over 30 months, the rate of decline in nematode populations with various starting populations and in a particular cropping sequence were monitored. High population of 80 nematodes/cm^3 (~80,000 Pt/kg) took four years to reduce below the threshold. This would require two non-host crops such as sorghum and fallows to reduce the population. A moderate initial population of 50 nematodes/cm^3 took three and a half years (Figure 2), requiring the equivalent of a single non-host summer crop and fallows. A population of 20 nematodes/cm^3 took 24 months.

The long survival mechanisms of root-lesion nematodes highlight the importance of knowing the size of the population at the end of each season. Once a population increases, non-host, resistant crops or fallows are required to reduce the population below the damage threshold. Planting susceptible or tolerant crops within this time period will increase populations to higher levels that will take longer to reduce, thereby limiting cropping options, and potentially reducing the profitability of the overall farming system. As resistant wheat varieties are released they can be used to provide a winter decline option to increase non-host periods within the rotation. [14]

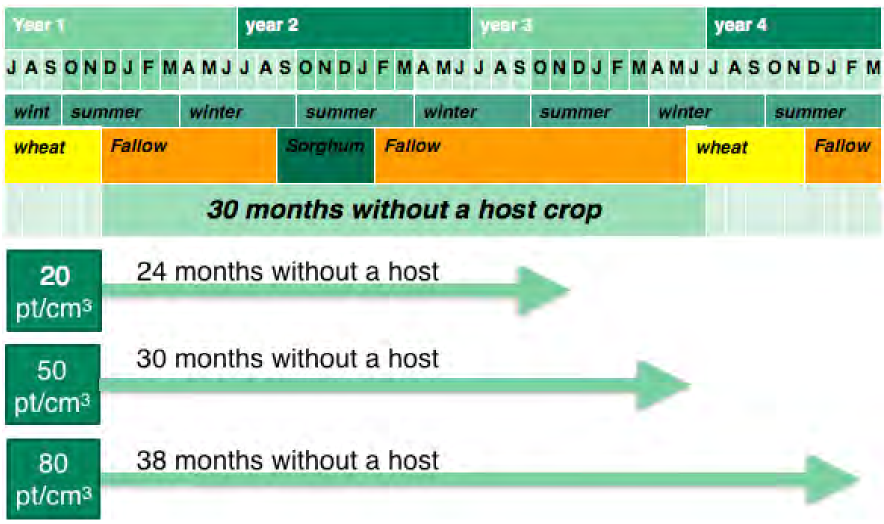


Figure 2: *An example of a non-host fallow showing the time required to reduce different starting populations of root-lesion nematode.*

Source: GRDC

MORE INFORMATION

How long does it take to reduce *Pratylenchus thornei* (Root lesion nematode) population in the soil?

14 J Which, J Thompson (2016) GRDC Update Paper: How long does it take to reduce *Pt* populations in the soil? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/how-long-does-it-take-to-reduce-Pratylenchus-thornei-populations-in-the-soil

8.1.6 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. [15]

8.1.7 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 *Pratylenchus thornei* (*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 RLN:

1. Have soil tested for nematodes in a laboratory.
2. Protect paddocks that are free of nematodes by controlling soil and water runoff and cleaning machinery; plant nematode-free paddocks first.
3. Choose tolerant wheat 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 (Figure 3, Table 2). 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.

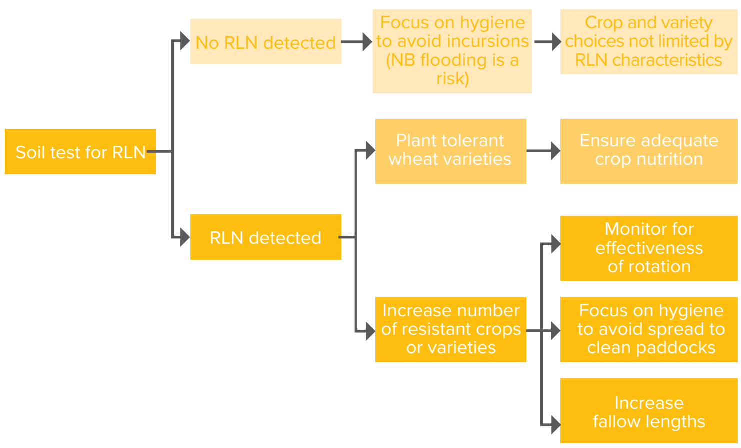


Figure 3: *RLN management flow chart—a simplified chart that highlights that the critical first step in the management of RLN is to test your soil and determine whether you have an issue to manage.*

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.

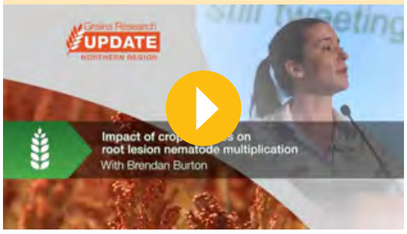
Source: GRDC

15 GRDC (2015) Tips and tactics: Root lesion nematodes southern region, www.grdc.com.au/TT-RootLesionNematodes

VIDEOS

WATCH: Root lesion nematodes—What can I do?

WATCH: Crop variety effect on nematode.



MORE INFORMATION

GRDC Tips and tactics: Root-lesion nematodes Southern Region.

Table 2: *Susceptibility of some non-cereal crop and pasture species to root lesion nematode infection. Cereal rye is thought to be resistant to P. neglectus.*

RLN Species	Susceptible	Moderately susceptible	Resistant
Pratylenchus neglectus	canola, chickpea, mustard	common vetch, lentil	field pea, narrow leaf lupin, faba bean, triticale, safflower, cereal rye, medic, clover
Pratylenchus thornei	chickpea, vetch, faba bean	canola, mustard, field pea, lentil	field pea, lupin

Source: Soilquality.org.

There are four major control strategies against RLN:

1. **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.
2. **Nutrition**: Damage from RLN reduces the ability of cereal roots to access nutrients and soil moisture and can induce nutrient deficiencies. Under fertilising is likely to exacerbate RLN yield impacts however over-fertilising is still unlikely to compensate for a poor variety choice.
3. **Variety choice and crop rotation:** *These are currently our most effective management tools for RLN.* However, the focus is on two different characteristics—*Tolerance* (ability of the variety to yield under RLN pressure) and *Resistance* (impact of the variety on the buildup of RLN populations). NB varieties and crops often have varied tolerance and resistance levels to *Pt* and *Pn*.
4. **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. [16]

8.2 Cereal Cyst Nematode (CCN)

Key points

- CCN is a threat to cereals in the Southern and Western growing regions.
- Rye is resistant to CCN, providing an alternative management approach for these diseases. [17]
- Rye can reduce the amount of CCN in a paddock. In one study, the biggest reduction in CCN numbers occurred in cereal rye (cv. South Australia), which reduced populations by 92% in the first year. [18]
- 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.
- Grow resistant cereal cultivars to limit levels of CCN in the soil.

16 B Burton, R Norton, R Daniel (2015) GRDC Update Paper: Root-lesion nematode; importance, impact and management. NGA, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

17 L Martin L (2015) Growing Cereal Rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

18 JM Fisher, TW Hancock (1991) Population dynamics of Heterodera avenae Woll. in south Australia. Crop and Pasture Science, 42(1), 53-68.

- 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.

CCN is a pest of graminaceous crops worldwide. This nematode is a significant problem across eastern Australia. CCN becomes more problematic in areas where intensive cereal cropping occurs. CCN will only infect, feed and develop on cereals and other grasses (particularly wild oat). Non-cereal crops will not host the nematode, so are useful in rotations to limit damage caused to cereals.

Cereal Rye is tolerant and will yield well despite being attacked.

CCN usually occurs early in the season and can occur on heavy or light soils.

IN FOCUS

The effect of plant hosts on populations of the cereal cyst nematode (Heterodera a Venae) and on the subsequent yield of wheat

Microplots containing soil, naturally infested with the cereal cyst nematode (*Heterodera avenae*) were left fallow or sown to one of nine cereal cultivars or grass species for five consecutive years. Wild oat was the most efficient host and, after three plantings, the nematode reached a potential increase ceiling of 42.2 eggs/g soil. Of the cereal cultivars tested, wheat (cv. Olympic) and barley (cv. Prior) were the most efficient hosts and levels of approximately 40 eggs/g were reached after five plantings. Barley grass was less efficient than Wimmera ryegrass, which maintained a ceiling population of about 10 eggs/g. Under fallow, populations declined to 0.5 eggs/g after four years. The most inefficient cereal hosts were the oat, cv. Avon, and cereal rye, cv. South Australian. The low populations maintained under continuous cropping with these cereals suggested that a rapid selection of a resistance-breaking biotype is unlikely to result from the continued use of inefficient hosts. Growth and yield of a subsequent wheat crop on all plots reflected the relative levels of nematode populations. At the low levels of infestation, grain yields were more than double those on heavily infested plots. [19]

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. CCN have only one life cycle per

19 JW Meagher, RH Brown, (1974) Microplot Experiments On the Effect of Plant Hosts On Populations of the Cereal Cyst Nematode (Heterodera a Venae) and On the Subsequent Yield of Wheat. Nematologica, 20(3), 337-346.

year (Figure 4). However, each cyst contains several hundred eggs, so populations can increase rapidly on susceptible cereals. [20]

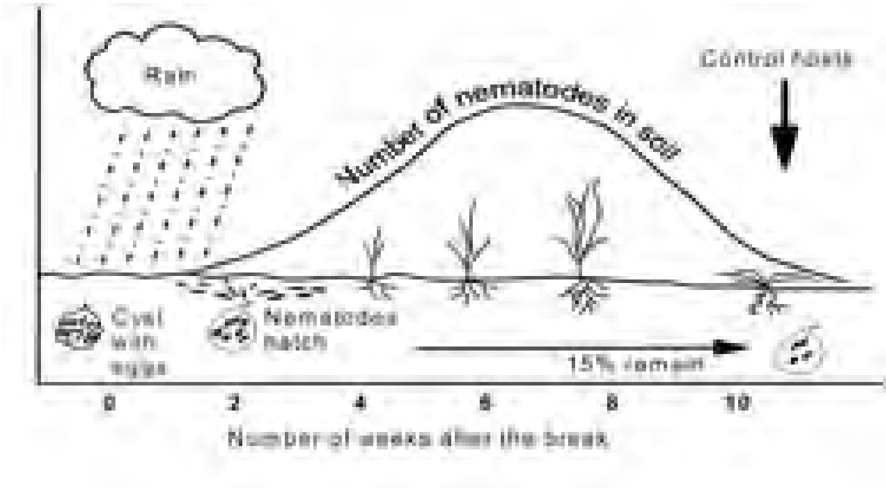


Figure 4: *Life cycle of the cereal cyst nematode.*

Source: AgVic

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 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. [21]

8.2.1 Symptoms and detection

The symptoms of CCN infection can be readily recognised. 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. [22]

20 A Wherrett V Vanstone V. Cereal cyst nematode. Soilquality.org, http://www.soilquality.org.au/factsheets/cereal-cyst-nematode

21 G Hollaway, F Henry (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

22 A Wherrett V Vanstone V. Cereal cyst nematode. Soilquality.org, http://www.soilquality.org.au/factsheets/cereal-cyst-nematode

Photo 5: *CCN will cause distinct patches of yellowed and stunted plants. Note the likeness of symptoms to poor nutrition or water stress.*

Photo: Vivien Vanstone, DAFWA, Nematology. Source: Soilquality.org

Photo 6: *CCN produce 'knotting' of cereal roots.*

Photo: Vivien Vanstone, DAFWA, Nematology. Source: Soilquality.org

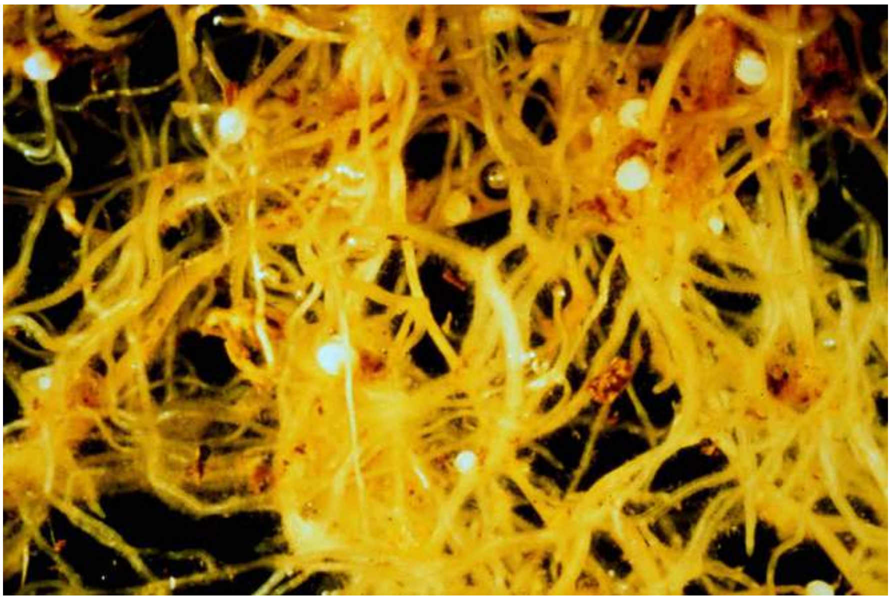


Photo 7: *Cereal roots infected with CCN appear "ropey" and swollen.*

Source: CropPro

8.2.2 Varietal resistance or tolerance

Rye is resistant to CCN, providing an alternative management approach for these diseases. [23]

8.2.3 Damage caused by CCN

In serious outbreaks of CCN, it may be important to avoid cereals for two years to ensure an adequate reduction in the population. Just two CCN eggs/g soil can cause significant economic loss to intolerant cereal crops. Levels of 1—5 eggs/g soil can reduce yield of intolerant cultivars by up to 20%. [24]

8.2.4 Management

In general, CCN has been well managed in Victoria through the widespread use of resistant cultivars.

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 4 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, such as the Wimmera and Mallee, 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.

23 L Martin (2015) Growing Cereal Rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

24 A Wherrett, V Vanstone (2016) Cereal Cyst Nematode, http://www.soilquality.org.au/factsheets/cereal-cyst-nematode

- 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 and 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 CCN and the planting of a cereal cannot be avoided, it is important to choose cultivars displaying CCN resistance. [25]

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. [26]

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 *Pratylenchus thornei* (*Pt)* levels. As well as reducing yield, *Pt* reduces grain quality and nitrogen use efficiency, and increases the severity of crown rot infections. [27]

There have been numerous field trials since 2007 evaluating the impact of crown rot on a range of winter-cereal crop types and varieties. This work has greatly improved the understanding of crown rot impact and variety tolerance, but also indicates that we may be suffering significant yield losses from another “disease” that often goes unnoticed.

Although the trials were not designed to focus on nematodes, a convincing trend was apparent after 2008 that indicated *P. thornei* was having a frequent and large impact on wheat variety yield. [28]

Where Pt combines with high levels of crown rot (a common scenario), yield losses can be exacerbated if varieties are susceptible to Pt. Instead of a 10% yield loss from

25 A Wherrett, V Vanstone. Cereal cyst nematode. Soilquality.org, http://www.soilquality.org.au/factsheets/cereal-cyst-nematode

26 GRDC (2016) Tips and Tactics: Crown rot in winter cereals—Southern region.

27 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

28 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

Pt in a susceptible variety, it could be 30–50% if crown rot is combined with a Pt-intolerant variety (Photo 8).

The research has also shown that not only does Pt cause high yield loss in susceptible varieties, but Pt numbers can increase much faster than in an area in which tolerant varieties are growing. These increased Pt numbers can lead to even greater damage in future crops. [29]

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.

8.3.1 Management

Variety choice is the key management option when it comes to managing Pt risk. However, when it comes to crown rot management, although varieties have some impact, rotation and stubble management are by far our most important management tools. RLN, especially Pt, need to be taken far more seriously and better factored into crop rotation considerations as well as variety choice. [30]

Soil testing

PreDictaB

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29 B Freebairn (2011) Nematodes and crown rot: a costly union. Ground Cover Issue 91, March-April 2011. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union

30 B Freebairn (2011) Nematodes and crown rot: a costly union. Ground Cover Issue 91, March-April 2011. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union

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*).
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- Blackspot of peas (*Mycosphaerella pinodes, Phoma medicaginis var pinodella* and *Phoma koolunga*).

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SARDI process PreDicta B samples weekly between February and mid-May (prior to crops being sown) every year.

These timeframes help assist growers with cropping programs.

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 RLN tolerance.

Further research into varietal tolerance to crown rot and nematodes has revealed that choosing a variety is difficult. Determining the relative tolerance of varieties to crown rot is complex as it can be significantly influenced by background inoculum levels, RLN populations, differential variety tolerance to *Pn* versus *Pt* and varietal interaction with the expression of crown rot. Other soil-borne pathogens such as *Bipolaris sorokiniana*, which causes common root rot, also need to be accounted for in the interaction between crown rot and varieties. Starting soil water, in-crop rainfall, relative biomass production, sowing date and resulting variety phenology in respect to moisture and/or temperature stress during grainfill can all differentially influence the expression of crown rot in different varieties. [31]

The approximate order of increasing yield loss to crown rot is: cereal rye, oats, barley, bread wheat, triticale and durum wheat. [32] There is limited research on the tolerance of cereal rye to *P. thornei.*

31 S Simpfendorfer, M Gardner, G Brooke, L Jenkins (2014) Crown rot and nematodes—are you growing the right variety? GRDC Update Papers 6 March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Crown-rot-and-nematodes

32 GRDC. (2016). Tips and Tactics: Crown rot in winter cereals. Southern region.

Diseases

Key messages

- Rye has good tolerance to cereal root diseases.
- The most important disease of rye is ergot (*Claviceps purpurea*). It is important to realise that feeding stock with ergot infested grain can result in serious losses. Grain with three ergots per 1,000 kernels can be toxic. [1]
- Stem and leaf rusts can usually be seen on cereal rye in most years, but they are only occasionally a serious problem. [2]
- All commercial cereal rye varieties have resistance to the current pathotypes of stripe rust. However, the out-crossing nature of the species will mean that under high disease pressure, a proportion of the crop (approaching 15–20% of the plant population) may show evidence of the disease. Other diseases are usually insignificant.
- Cereal rye has tolerance to take-all, making it a useful break crop following grassy pastures. [3]
- Bevy is a host for the root disease take-all and this should be carefully monitored. [4]

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. [5]
- Stay up to date with local disease guides: Cereal disease guide 2016–SA and Cereal disease guide 2016–Vic

1 HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

2 Agriculture Victoria (2013) Growing Cereal Rye, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

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

4 Agriculture Victoria. (2013). Growing Cereal Rye. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

5 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 app 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 precursor for this app was the Victorian DEDJTR Crop Disease app developed by a team of grains pathologists. 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

Web-based

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

MORE INFORMATION

[MyCrop]

[GRDC Cereal root and crown diseases: Back pocket guide.]

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.

9.2 Ergot

The most important disease of rye is ergot (*Claviceps purpurea*). Ergot, a purplish, black fungal disease that makes grains unsafe for consumption, is a prevalent problem in cereal rye crops.

Ergot produces black growths called sclerotia, which are visible in the heads of the rye (Photo 1). The fungi infect young, usually unfertilised ovaries, replacing the seeds by dark mycelial masses (sclerotia). Usually, ergot infestations affect the borders of rye fields first, so it is important to take note of ergot and harvest infested sections of the field separately, especially if you are saving rye seed for next years' crop.

Photo 1: *Ergot (sclerotia) bodies taken from rye grain head.*

Source: Botany Hawaii

Good crop rotation practices will minimize the chances of damage from disease, but rye crops should always be tested before human consumption. [6]

Ergot occurs throughout the world and affects many grass species, including cultivated cereals. Ergot is relatively rare in Australian grains, however it is considered a constant threat as it contains toxic chemicals (alkaloids) that are very harmful to both animals and humans. For this reason, ergot in grain could prove quite damaging to our trade. [7]

Ergot produces alkaloids similar to the psychotomimetic drug LSD. Two types of Sweet Scabious intoxication have been reported: gangrenous ergotism, from

6 UVM (2011) Cereal Rye, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

7 AWB. Wheat Quality Factsheet—ERGOT, https://www.awb.com.au/NR/rdonlyres/BFA96F0A-1967-4B8D-8B6C-631A00F15478/0/ERGOT_factsheet.pdf

consuming small amounts over a long period, and convulsive ergotism, which affect both people and animals. Grain with three ergots per 1,000 kernels can be toxic. [8]

When using grain with known low levels of ergot from a silo it is important to continue to monitor the concentration of ergot, because it is often in highest concentration in the last 10% of silo content. [9]

For information on the history of this disease, see Ergot of rye.

9.2.1 Varietal resistance or tolerance

Cereal rye and many grass species (including ryegrass) are particularly susceptible to ergot because they are open flowered species.

9.2.2 Damage caused by disease

Ergot bodies contain alkaloid chemicals that can cause lameness, gangrene of the extremities and nervous convulsions (staggers). This 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. [10]

Gangrenous ergotism of man and cattle

Symptoms: 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, symptoms include 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 are followed by painful spasms of the limbs, epileptic convulsions and delirium in humans. Cattle become excitable and run with a swaying, uncoordinated gait. [11]

9.2.3 Crop symptoms

Characteristically ergot pieces have a purple—black surface with a white to grey interior (Photo 2). 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. [12]

8 HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

9 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

10 AWB. Wheat Quality Factsheet—ERGOT, https://www.awb.com.au/NR/rdonlyres/BFA96F0A-1967-4B8D-8B6C-631A00F15478/0/ERGOT_factsheet.pdf

11 HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Rye.htm

12 DAFWA (2015) Diagnosing Ergot, https://www.agric.wa.gov.au/mycrop/diagnosing-ergot

Photo 2: *Ergot bodies in rye grain head.*

Source: Natgeocreative

In stock

Producers are encouraged to keep an eye on animals eating ergot-infected grain in hot or sunny weather (Photo 3). 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. [13]

Photo 3: *Producers need to be aware that even a small amount of ergot in grain can cause serious illness to their stock.*

Photo: Michael Raine, Source: WCVM

13 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

9.2.4 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 rainsplash 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. [14]

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. 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. [15]

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. [16]

9.2.5 Management of disease

Key points

- Give contaminated paddocks a one-year break without cereals or grasses.
- Manage grass weed contamination in crops.
- Seed cleaning. [17]

For grain that is contaminated with pieces of ergot, grain-cleaning equipment can be used to remove the majority of ergot bodies (Photo 4). However, the grower will need to determine whether this is an economically viable option.

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14 DAFWA (2015) Diagnosing Ergot, https://www.agric.wa.gov.au/mycrop/diagnosing-ergot

15 AWB. Wheat Quality Factsheet—ERGOT, https://www.awb.com.au/NR/rdonlyres/BFA96F0A-1967-4B8D-8B6C-631A00F15478/0/ERGOT_factsheet.pdf

16 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

17 DAFWA (2015) Diagnosing Ergot, https://www.agric.wa.gov.au/mycrop/diagnosing-ergot

Photo 4: *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 are 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. [18]

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. [19]

There are no ergot resistant rye varieties. The only practical control is to sow clean, year-old seed on land that hasn't grown 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. [20]

18 AWB. Wheat Quality Factsheet—ERGOT, https://www.awb.com.au/NR/rdonlyres/BFA96F0A-1967-4B8D-8B6C-631A00F15478/0/ERGOT_factsheet.pdf

19 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

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

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. [21]

Marketing options

Stockfeed intended for feedlot cattle has been further limited to 0.1% sclerotes by weight since 2004.

Deliveries of grain 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 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 grain 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 grain that contains 0.3% sclerotes. Grain 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. [22]

IN FOCUS

Alkaloids in Australian rye ergot sclerotia: implications for food and stockfeed regulations.

Rye ergot (*Claviceps purpurea*) occasionally causes toxicity (chiefly expressed as hyperthermia) in Australian livestock, either as a result of grazing infected annual (*Lolium rigidum*) and perennial (*L. perenne*) rye grasses, or if the ergot sclerotia produced in rye grasses contaminate grain crops used as stockfood. Alkaloids in 30 samples of Australian rye ergot sclerotia taken from rye grasses and grain screenings, and some feed samples contaminated with rye grass ergot sclerotia, were assayed by high performance liquid chromatography.

Bulk grain traders limit rye ergot sclerotia by length (laid end to end), for example the maximum limits set by Grain Trade Australia for 2009–10 for rye ergot sclerotia per half litre of grain were: wheat, 2 cm; barley, 0.5 cm; oats, 2 cm; triticale, nil; rye, nil. Rye ergot sclerotia are restricted to 0.02% (w/w) in grain under Stockfood Regulations—a limit set many years ago on very limited toxicological data. The limit of 0.02% (200 mg ergot/kg) is roughly equivalent to 8 cm rye ergot sclerotia per half litre of grain, based on the average weights and lengths of sclerotia assayed here.

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

22 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

In regard to livestock, sun-exposed ruminants are more sensitive to the effects of ergot than humans and other monogastric animals. The few cases of livestock poisoning reviewed here, and the limited experiments reviewed, show severe hyperthermia in ruminants fed 1–2 mg ergot alkaloids/kg of feed, suggesting that the total alkaloid content of feed should be restricted at least to <0.5 mg/kg. An extra safety margin is desirable to allow for irregular distribution of ergot sclerotia in bulk grain, and variations in individual susceptibility to ergot, so <0.1 mg/kg appears a reasonable target. This equates to ~0.004% rye ergot sclerotia (40 mg/kg) for sclerotia having an alkaloid content of around 2500 mg/kg (<2 cm sclerotia per half litre of grain). However, other risk factors include the unknown role of the ergot pigments in exacerbating hyperthermia in sunlight-exposed stock. All these variables combine to indicate that feed likely to contain any detectable rye ergot should be avoided for ruminant feedlot rations. Poultry and non-lactating mature (finisher) pigs present better options for use of lightly contaminated grain than ruminants. [23]

9.3 Take-all

Key points:

- Take-all is a fungal disease of the roots of cereals.
- 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 (when and how much?) 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.

Take-all is a soil borne disease of cereal crops and is most severe on crops throughout southern Australia. The disease 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 that minimise carry-over of the disease from one cereal crop to the next. [24]

Cereal rye's resistance and tolerance to take-all (except for the variety Bevy) makes it a useful break crop for sowing before susceptible wheat, triticale or barley crops. It can also be sown in situations where take-all is expected—following grassy pasture on soils that are unsuitable for oats. [25]

However, one study from New Zealand suggests that rye may increase take-all inoculum.

- While rye is regarded as resistant to the root disease take-all, recent work has shown it can result in high levels of take-all inoculum.

23 BJ Blaney, JB Molloy, IJ Brock (2009) Alkaloids in Australian rye ergot (Claviceps purpurea) sclerotia: implications for food and stockfeed regulations. *Animal Production Science*, *49*(11), 975-982.

24 Soilquality.org (2016) Take-all Disease—NSW. http://www.soilquality.org.au/factsheets/take-all-disease-nsw

25 Wrighton Seeds. Forage Focus—Southern Green Ryecorn, http://www.pggwrightsonseeds.com.au/assets/FTP-Uploads/Forage_Focus/Cereals/FF_Southern-Green-Forage-Ryecorn.pdf

- Wheat and barley roots are both infected by take-all, but effects on wheat are usually more serious. Rye is generally resistant to take-all. Triticale, depending on the parentage of the cultivar, ranges from; being almost as susceptible as wheat to as resistant as rye.
- Take-all is caused by the fungus *Gaeumannomyces graminis*var. *tritici* (*Ggt).*
- A recent field trial has confirmed that wheat is more susceptible to take-all than rye, triticale and barley. The triticale cv. "Kortego" was more resistant than barley (cv. "Quench"), while rye had no visible infection by take-all. The results support the selection of rye, triticale and barley over wheat for growing in fields known to have *Ggt*.
- Although barley, triticale and rye do not become heavily infected by take-all, levels of *Ggt* in the soil after these cereals can be high. The large root systems of these species may provide more material for infection and *Ggt* inoculum build-up.
- Growers are keen to keep cropping rotations flexible. This research shows that the risk to take-all in wheat cannot be reduced by using barley, triticale and rye as break crops between wheat crops. [26]

Ggt is the main cause of take-all, and its hosts include Bevy rye, wheat, barley and the grassy weeds, barley grass and broom grass. *Gga* hosts include all *Ggt* hosts plus oat. Both fungi survive over summer on roots and crowns of infected plants. *Gga* and *Ggt* levels are reduced by significant summer rainfall, but high available nitrogen in soil over summer encourages inoculum survival.

Take-all can cause large yield losses, especially in wheat crops in seasons with above average winter/early spring rainfall followed by moisture stress around anthesis. The risk increases with consecutive above average rainfall seasons in intensive cereal and cereal/grass pasture rotations. Losses in barley are generally about 50% of those in wheat. Take-all is rarely a problem in highly acid soils (pH <5.5 in water; pH <4.7 in $CaCl_2$). [27]

9.3.1 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 is symptomatic of an early take-all infection. Severely infected plants will have a blackened crown and stem base and will 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 whiteheads later in the season is another indicator of take-all (although frost and micronutrient deficiencies can also cause whiteheads) 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. [28]

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 5).
- Affected plants can be individuals scattered among healthy plants or entire populations of plants over a large area.

26 Foundation for Arable Research (2009) High take-all inoculum levels can follow resistant cereals, https://www.far.org.nz/assets/files/uploads/C194Take-all.pdf

27 A McKay. Take-all—South Australia. Soilquality.org, http://www.soilquality.org.au/factsheets/take-all-sa

28 Soilquality.org (2016) Take-all Disease—NSW, http://www.soilquality.org.au/factsheets/take-all-disease-nsw

Photo 5: *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 6).
- Severely affected plants can also have blackened crowns and lower stems.

Photo 6: *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

9.3.2 Conditions favouring development

Gaeumannomyces graminis survives the Australian summer in the residue of the previous season's grass host (Figure 1). 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. Higher rainfall in winter is likely to increase take-all disease pressure. 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.

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.

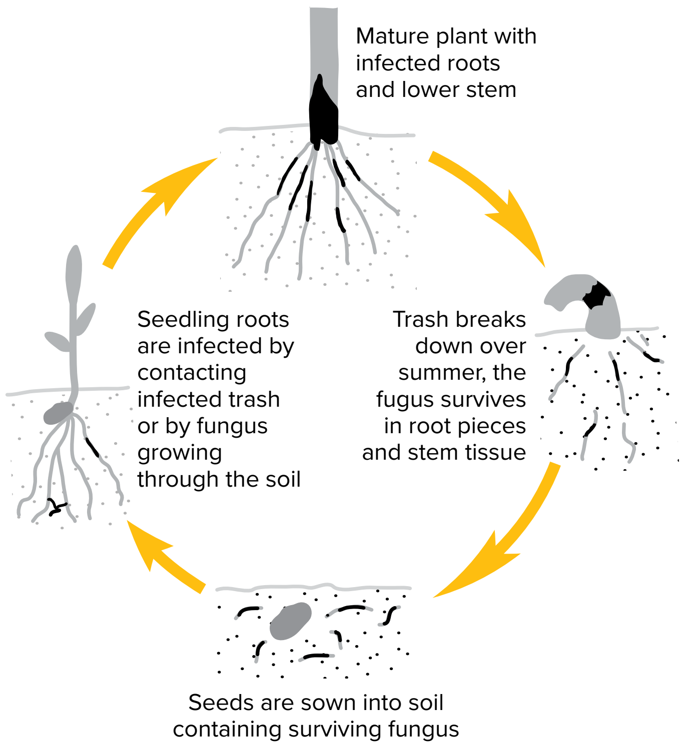


Figure 1: *Common life cycle of the take-all fungus in Western Australian cropping regions*

Adapted from MacNish (2005) Source: Soilquality.org

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 one of 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. [29]

9.3.3 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.
- Cereal rye's resistance and tolerance to take-all (except for the variety Bevy) makes it a useful break crop for sowing before susceptible wheat, triticale or barley crops. It can also be sown in situations where take-all is expected—following grassy pasture on soils that are unsuitable for oats. [30]
- Seed, fertiliser or in-furrow applied fungicides are registered for take-all control.
- Acidifying fertilisers can slightly reduce disease severity (take-all severity may increase following liming).

29 Soilquality.org (2016) Take-all Disease—NSW, http://www.soilquality.org.au/factsheets/take-all-disease-nsw

30 Wrighton Seeds. Forage Focus—Southern Green Ryecorn, http://www.pggwrightsonseeds.com.au/assets/FTP-Uploads/Forage_Focus/Cereals/FF_Southern-Green-Forage-Ryecorn.pdf

- Control volunteer grasses and cereals.
- Delay sowing following the opening rains by implementing a short chemical fallow. [31]

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) 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, and has been shown to occur in South Australia. 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. [32]

9.4 Rusts

In Australia, there are three rust diseases of rye 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 that 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 wheat, triticale 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.

31 DAFWA (2015) Diagnosing Take-all in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-take-all-cereals

32 Soilquality.org (2016) Take-all Disease—NSW, http://www.soilquality.org.au/factsheets/take-all-disease-nsw

Plants facilitating the survival of rust fungi through the summer are known as the 'green bridge'. [33]

Given favourable conditions stripe 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.

Stripe rust reached epidemic levels in eastern Australia during 2009, resulting in widespread fungicidal spraying.

In the most recent cereal rust report, a sample of Rye leaf rust was received from Borrika in SA in late July 2016. [34]

9.4.1 Symptoms

Use Table 1 and the descriptions and figures below to help diagnose the differing types of rust in Australia.

Table 1: *Diagnosing leaf diseases in cereals.*

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 leaf 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

9.4.2 Stripe rust (Yellow rust)

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 7).

33 DAF (2015) Wheat-diseases, physiological disorders and frost, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

34 W Cuddy, R Park, D Singh (2016) Cereal rust situation, September 2016. USYD, http://sydney.edu.au/agriculture/documents/pbi/cereal_rust_report_2016_14_7.pdf

Photo 7: *Stripe rust in cereal plant.*

Source: DAFF

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 moderately susceptible or susceptible. 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 onset of disease (Table 2 and 3). Later on, if the main leaves (the flag, flag 1, -2 and -3 leaves) require protection, recommended foliar fungicides can be applied for the control of stripe rust.

Samples have been received from Victoria including a sample off Derrimut from Nullawil and a sample off Scepter from Rupanyup. Stripe rust has been reported by Dr Hugh Wallwork around the Northern Yorke Peninsula in SA, but no samples have yet been received to confirm its presence. [35]

Stripe rust in southern Australia

There have been two introductions of stripe rust into Australia. These introductions may have entered on clothing. The first introduction occurred in Victoria in 1979, and it rapidly spread across eastern Australia. This original rust mutated, and a number of pathotypes (also known as races or strains) developed enabling the rust to attack more varieties over time. This first introduction, even though widespread in the eastern Australia, did not move to Western Australia.

The second introduction of stripe rust into Australia occurred in WA in 2002. By 2003, this pathotype was in eastern Australia. This second introduction, now known as the "WA" pathotype, quickly became dominant in eastern Australia. Since 2003 the "WA" pathotype has undergone several mutations in eastern Australia. There are now many pathotypes of stripe rust that are common in southern Australia. The

MORE INFORMATION

Stripe rust

35 W Cuddy, R Park, D Singh (2016) Cereal rust situation, September 2016, http://sydney.edu.au/agriculture/documents/pbi/cereal_rust_report_2016_14_7.pdf

VIDEOS

WATCH: GCTV1: Cereal Rust.

resistance ratings provided in disease guides often represent the most important of the pathotypes. [36]

9.4.3 Leaf rust (Brown rust)

Leaf rust is caused by the fungus *Puccinia triticinia* (previously called *Puccinia recondite* f. sp. *tritici*). The disease can infect rye, wheat and triticale.

Leaf rust produces reddish-orange coloured spores, occurring 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 that is found on both surfaces of the leaf (Photo 8).

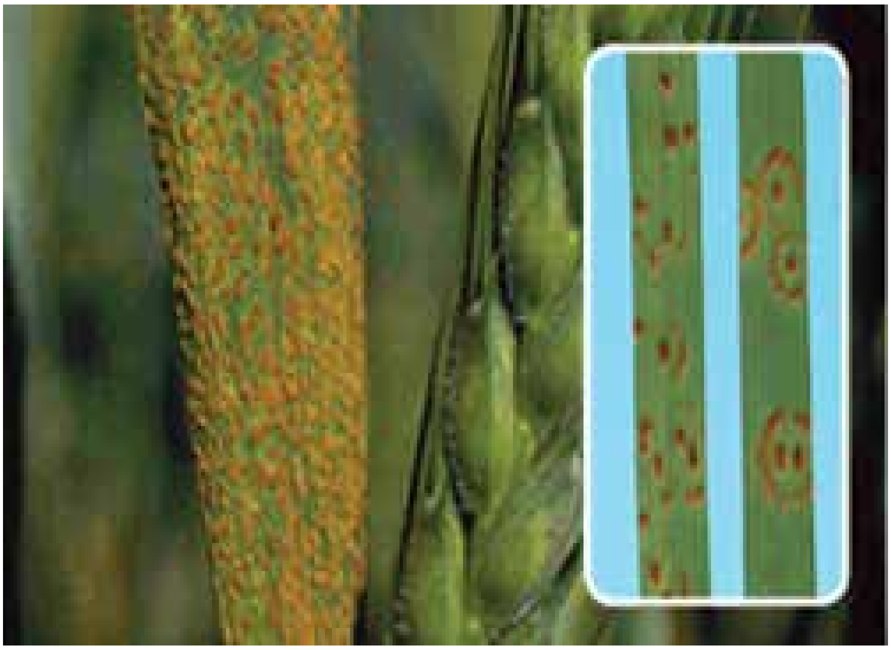


Photo 8: *Leaf rust in cereal plant.*

Source: DAFF

In most parts of southern Australia leaf rust is effectively controlled with resistant varieties, but it can cause problems in areas where susceptible varieties are grown. Cereal varieties mostly have reasonable resistance (ratinsg of moderately resistant, moderately tolerant or better).

The spores require 15–20°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.

Find out about the use of foliar fungicides to control leaf rust (Table 3 in sections below).

Samples of leaf rust have been received from all wheat growing states except Tasmania (Figure 2). Since the last Issue, a further sample of wheat leaf rust has been received from Lismore in Victoria, but no further samples have been received from the state. Samples from SA have been received from Port Neill off the variety Mace, and off other wheats from Paskeville and Roseworthy in late August and early September 2016. A sample of Rye leaf rust was received from Borrika in South Australia in late July. [37]

36 G Holloway (2016) Stripe rust of wheat, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/stripe-rust-of-wheat

37 W Cuddy, R Park, D Singh (2016) Cereal rust situation, September 2016, http://sydney.edu.au/agriculture/documents/pbi/cereal_rust_report_2016_14_7.pdf

MORE INFORMATION

Leaf rust

Figure 2: *Reported detections of leaf rust in 2016.*

Source: USYD

9.4.4 Stem rust (Black rust)

Stem rust is caused by the fungus *Puccinia graminis* f. sp. *tritici*. In addition to rye, it can also attack wheat, barley and triticale.

Stem rust produces reddish-brown spore masses in oval, elongated or spindle-shaped pustules on the stems and leaves. Unlike leaf rust, pustules erupt through both sides of the leaves (Photo 9). Ruptured pustules release masses of stem rust spores, which are disseminated by wind and other carriers.

Photo 9: *Stem rust in cereal plant.*

Source: DAFF

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. 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 that has overcome a variety'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 presented in Table 2 and 3, in the sections below.

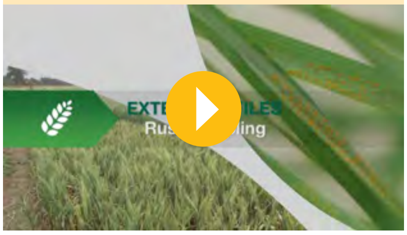
MORE INFORMATION

Stem rust

VIDEOS

WATCH: GCTV5: Green Bridge control for less stem rust.

WATCH: GCTV Extension Files: Rust Sampling.



Stem rust in southern Australia

Conditions that favour stem rust epidemics are rare and occur on average once every 16 years in southern Australia. However, when conditions are conducive, the disease can cause complete crop loss in susceptible varieties.

Historically, the most severe epidemics occurred (in descending order of severity) in 1973, 1947, 1934 and 1955. In 1973, stem rust reduced the southern cereal harvest by 25%. It is unlikely that stem rust losses will ever be as severe as in 1973 due to the increased cultivation of stem rust resistant varieties and the greater availability of effective foliar fungicides. In recent years, there have been few localised occurrences of stem rust.

Following the exceptionally wet January of 2011 there was a large amount of inoculum carry over that resulted in widespread stem rust in southern Australia during 2011. Despite this, the widespread use of chemicals helped minimise losses from this disease. [38]

9.4.5 Management of Rust

Rust diseases in cereals can be eliminated or significantly reduced by removing this green bridge. This should be done well before the new crop is sown, allowing time for any herbicide to work and for the fungus to stop producing spores.

Rust fungi continually change, producing new pathotypes. These pathotypes are detected when disease is found on a previously resistant variety. Even if a resistant variety has been sown, the crop should be monitored for foliar diseases on a regular basis.

This should start no later than growth stage 32, the second node stage on the main stem and continue to at least growth stage 39, the flag leaf. This is because the flag leaf and the two leaves below it are the main factors contributing to yield and quality. It is very important that these leaves are protected from diseases. [39]

38 G Hollaway (2014) Stem rust of wheat, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/stem-rust-of-wheat

39 DAFF QLD. Wheat—diseases, physiological disorders and frost, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

9.4.6 Integrated disease management of rusts and yellow leaf spot

Key points

- Destroy volunteer 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 leaf 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 your local DPI'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, and 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, consult your agronomist or local DPI.

Rust diseases occur throughout the cereal growing southern regions, frequently causing economic damage.

Wherever possible, sow resistant varieties MR (Moderately Resistant = 6) and above.

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 main leaves (the flag, flag 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.

There are a number of fungicides recommended for the control of foliar diseases of cereals (Table 2 and Table 3).

Table 2: *Fungicides recommended for seed/fertiliser treatment.*

Diseases	Fungicides	
	Fluquinconazole (167 g/L)	Flutriafol (250 g/L)
Stripe rust (Yellow rust)	Rate of product formulation: 450 ml/100 kg seed.	Rate of product formulation: 200 or 400 ml/ha Fertiliser.
Leaf rust (Brown rust)	Rate of product formulation: 450 ml/100 kg seed.	
Withholding periods after treatment	12 weeks for grazing and harvest.	4 weeks for grazing and harvest.

Source: DAFF

Table 3: *Rate of fungicide (product formulation) recommended as foliar sprays for the control of yellow leaf spot and rust diseases of cereals.*

Diseases	Foliar Fungicides							
	Epoxi-conazole (125 g/L)	Flutriafol (250 g/L)	Propi-conazole (250 g/L)	Triadimefon (125 g/L)	Tebu-conazole (430 g/L)	Prothio-conazole (210 g/L) + Tebu-conazole (210 g/L)	Azoxy-strobin (200 g/L) + Cypro-conazole (80 g/L)	Propi-conazole (250 g/L) + Cypro-conazole (80 g/L)
Stripe rust (Yellow rust)	250-500 ml/ha	250–500 ml/ha	250–500 ml/ha	500 or 1000 ml/ha	145 or 290 ml/ha	150–300 ml/ha + Hasten 1% v/v	400 or 800 ml/ha	250–500 ml/ha
Leaf rust (Brown rust)	500 ml/ha	250–500 ml/ha	150–500 ml/ha		145 or 290 ml/ha	150–300 ml/ha + Hasten 1% v/v	400 or 800 ml/ha	150–500 ml/ha
Stem rust (Black rust)			500 ml/ha		145 or 290 ml/ha	150–300 ml/ha + Hasten 1% v/v		500 ml/ha
Yellow leaf spot (Tan spot)			250–500 ml/ha		145 or 290 ml/ha	150–300 ml/ha	400 or 800 ml/ha	250–500 ml/ha
Withholding Periods	6 weeks for grazing and harvest	7 weeks for grazing and harvest	4 weeks for harvest, 7 days for grazing	4 weeks for grazing and harvest	5 weeks for harvest, 14 days for grazing	5 weeks for harvest, 14 days for grazing	6 weeks for harvest, 21 days for grazing	6 weeks for harvest, 21 days for grazing

Source: DAFF

MORE INFORMATION

CSIRO Cereal rusts

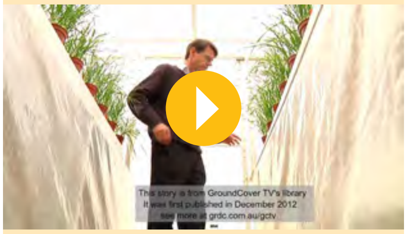
Rust Bust.

How to manage rust SA

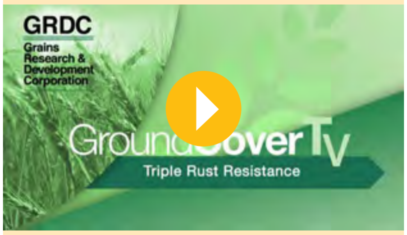
VIDEOS

WATCH: Adult plant resistance – fungicide.

WATCH: Cereal Rust – Adult plant resistance.



WATCH: GCTV18: Triple Rust Resistance.



WATCH: GCTV2: Yellow or Tan spot.

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. [40]

9.5 Yellow leaf spot (Tan spot)

Yellow leaf spot, also known as tan spot, has become a widespread and important disease of cereals in southern Australia. It has been supported by stubble retention, intense wheat production in the rotation and wide spread cultivation of susceptible varieties. [41]

Yellow leaf spot is caused by the fungus *Pyrenophora tritici-repentis*. It survives in wheat and occasionally triticale stubble. In rare cases, the fungus may survive in barley stubble. Wet spores (ascospores) develop in fungal fruiting bodies on wheat stubble, spread during wet conditions and can infect growing wheat plants.

As the crop develops, masses of a second type of spore (conidia) are produced on old lesions and dead tissues. Conidia result in rapid development of the epidemic within a crop and spread of the disease to other crops and areas. Again, wet conditions are necessary for spore production and infection. Strong winds are needed to spread the disease any great distance. [42]

40 RF Park, (2008) Breeding cereals for rust resistance in Australia. Plant Pathology, 57(4), 591-602.

41 G Holloway (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

42 DAFF QLD. Wheat—diseases, physiological disorders and frost, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

9.5.1 Varietal resistance or tolerance

Cereal Rye is partially susceptible. [43]

9.5.2 Damage caused by disease

Yellow 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. [44] 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 yellow 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.

9.5.3 Symptoms

Tan-brown flecks turning into yellow-brown oval-shaped spots/lesions surrounded by yellow margins, may expand into 10–12 mm in diameter. Large lesions coalesce with dark brown centres. Spot develops on both sides of leaves (Photo 10). Severe yellow leaf spot may result in short, spindly plants with reduced tillering and root development. Where conditions are favourable, plants may be fully defoliated soon after flowering. [45]

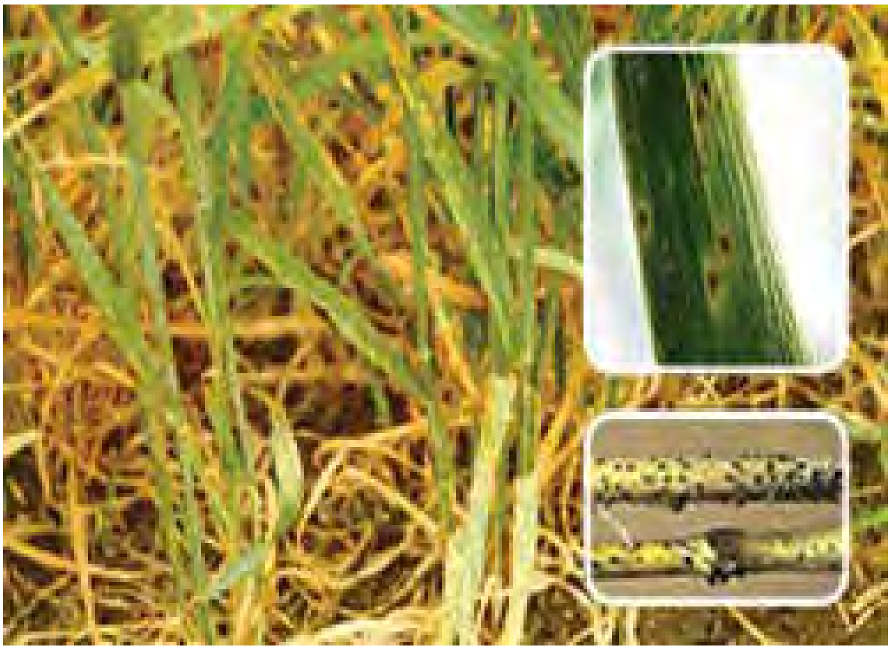


Photo 10: *Yellow/Tan spot in a cereal plant.*

Source: DAFF

9.5.4 Conditions favouring development

Yellow leaf spot is likely to develop in wet years in fields where cereal residues remain on the soil surface. Temperatures of 15°C to 28°C, with up to 12 hours of leaf wetness, are optimal conditions for infection. [46]

43 HerbiGuide, http://www.herbiguide.com.au/Descriptions/hg_Yellow_Spot_of_Wheat.htm

44 G Holloway (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

45 DAFF QLD. Wheat—diseases, physiological disorders and frost, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

46 GRDC (2011) Management to reduce the risk of yellow leaf spot—southern region Factsheet.

9.5.5 Management of disease

The impact of the disease can be reduced by:

- Planting partially resistant varieties.
- Rotation with resistant crops such as barley, oats or chickpea.
- Incorporation of stubble into the soil.
- Grazing or burning the stubble late in the fallow period.

Incorporation or burning stubble is not recommended unless infestation levels are very high. Correct identification of the yellow leaf spot fungus in infected stubble should be carried out before the stubble is removed. Varieties partially resistant to yellow leaf spot offer the only long-term solution, and should be considered for planting where yellow leaf spot could be a problem. [47]

Minimising the risk of yellow leaf spot

- Avoid sowing wheat-on-wheat.
- If you are going to sow wheat-on-wheat consider a late (autumn) stubble burn, and/or select a wheat variety with some level of resistance to yellow leaf spot (however, consider tolerance/resistance to other diseases as well).
- Primary management decisions for yellow leaf spot need to be made prior to and/or at sowing. Fungicides are a poor last resort for controlling yellow leaf spot as they have reduced efficacy. [48]

In-crop fungicides and timing

Fungicides used against yellow leaf spot in Australia include:

- Propiconazole
- Tebuconazole
- Azoxystrobin + Cyproconazole
- Propiconazole + Cyproconazole.

Timing for applying the chosen fungicide is crucial. The most effective time of application is at 90% flag leaf emergence with disease levels of less than 10% on the flag leaf.

See Tables 2 and 3 in the section above for fungicide options.

The higher rate of application has been shown to provide longer protection under periods of high disease pressure. Fungicide effectiveness is greater on susceptible varieties and is reduced with increasing levels of resistance.

Information on fungicide effectiveness has been gathered from irrigated field trials and does not confirm the economic viability of such applications during the extreme pressure of large-scale epidemics. [49]

Check the APVMA website for fungicide updates.

9.6 Fusarium: Crown rot and FHB

Key points

- 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.

MORE INFORMATION

Management of yellow leaf spot in wheat: decide before you sow.

Management to reduce the risk of yellow leaf spot—southern region Factsheet

Yellow leaf spot—is it worth spraying?

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47 DAFF QLD. Wheat—diseases, physiological disorders and frost, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

48 S Simpfendorfer (2013) GRDC Update Papers: Management of yellow leaf spot in wheat: decide before you sow, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Management-of-yellow-spot-in-wheat-decide-before-you-sow

49 DAFF QLD. Wheat—diseases, physiological disorders and frost, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

- 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.

There are two types of fusarium disease that affect cereal crops, Fusarium head blight (FHB) and crown rot (CR).

FHB is usually caused by the fungus *Fusarium graminearum* but the crown rot fungus *Fusarium pseudograminearum* may cause the disease in wet years as rainsplash distributes the fungus from lower stem nodes into grain heads.

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. [50]

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.

9.6.1 Update on the latest research

Take home messages

- 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 crown rot infected residue across paddocks and deeper into the soil.
- 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.

Crown rot, caused predominantly by the fungus *Fusarium pseudograminearum* is a significant disease of winter cereals. 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. It is critical that growers understand that there are three distinct and separate phases of crown rot, namely *survival, infection* and *expression*. Management strategies can differentially effect each phase.

Survival: The crown rot fungus survives as mycelium (cottony growth) inside winter cereal (wheat, barley, durum, triticale and oats) and grass weed residues, which it has infected. The crown rot fungus will survive as inoculum inside the stubble for as long as it remains intact, which varies greatly with soil and weather conditions as decomposition is a *very slow* process.

Infection: Given some level of soil moisture the crown rot fungus grows out of stubble residues and infects new winter cereal plants through the coleoptile, sub-crown internode or crown tissue which are all below the soil surface. The fungus can also infect plants above ground *right at* the soil surface through the outer leaf sheathes.

50 GRDC (2016) Tips and Tactics: Crown rot in winter cereals—Southern region.

However, with all points of infection, direct contact with the previously infected residues is required and infections can occur throughout the whole season given moisture. Hence, wet seasons favour increased infection events by the crown rot fungus when combined with the production of greater stubble loads significantly builds-up inoculum levels.

Expression: Yield loss is related to moisture/temperature stress around flowering and through grain-fill. This stress is believed to trigger the crown rot fungus to proliferate in the base of infected tillers, restricting water movement from the roots through the stems, and producing whiteheads that contain either no grain or lightweight shrivelled grain. The expression of whiteheads in plants infected with crown rot (i.e. still have basal browning) is restricted in wet seasons and increases greatly with increasing moisture/temperature stress during grain-fill. Focus attention to crops around trees within a paddock or along tree lines. Even in good years whiteheads associated with crown rot infection are likely to be seen around trees. This is due to the extra competition for water.

9.6.2 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 11). 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% possible at high inoculum levels, and losses in durum up to 90%.

Photo 11: *Scattered whiteheads leading to large yield losses in cereal crops.*

Source: DAFWA

9.6.3 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.

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 12). 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 13). 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 14).
- Pinched grain at harvest. [51]

Photo 12: *Honey-brown discolouration of stem bases.*

Source: DAFWA

51 Soilquality.org (2016) Crown rot—QLD, http://www.soilquality.org.au/factsheets/crown-rot-queensland

Photo 13: *Scattered single tillers and white heads.*

Source: DAFWA

Photo 14: *Pink discolouration often forms around or in the crown or under leaf sheaths.*

Source: DAFWA

9.6.4 FHB symptoms

FHB is an infection of the head rather than root or crown, as with Crown rot (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 15). Salmon pink to orange spore masses (sporodochia) at the bases of infected spikelets can also be apparent during prolonged warm, humid weather. Infected grains have a chalky white appearance and are usually shrivelled and lightweight; they may sometimes have pink staining too.

Photo 15: *Heads are partly or fully bleached.*

Source: DAFWA

9.6.5 Conditions favouring development

Crown rot

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 grainfilling 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. [52]

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. [53]

Interaction with root-lesion nematodes

Root-lesion nematodes (RLNs) are also a widespread constraint to wheat production across the region. RLNs feed inside the root systems of susceptible winter cereals and create lesions that reduce lateral branching. This reduces the efficacy of the root system to extract soil water and nutrients, which can subsequently exacerbate the expression of crown rot. Varieties with reduced tolerance to *Pratylenchus thornei* can

52 Soilquality.org (2016) Crown rot: Qld. Factsheet, Soilquality.org, http://www.soilquality.org.au/factsheets/crown-rot-queensland

53 T Dixon (2013) Balancing crown rot and nematodes in wheat. Ground Cover. No. 104, May–June 2013. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-104-May-June-2013/Balancing-crown-rot-and-nematodes-in-wheat

suffer significantly greater yield loss from crown rot if both of these pathogens are present within a paddock.

See Section 8.3 Nematodes and crown rot in Section 8: Nematodes for more information.

FHB

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.

9.6.6 Management

Key points:

- *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.
- *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. [54]

The disease may be controlled through planting more resistant varieties and using 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. [55]

Photo 16: *The GRDC's "Stop the crown rot" campaign.*

Source: GRDC

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: canopy density and rate of the canopy closure as well as row spacing, the amount of soil water they use and seasonal rainfall.

54 GRDC (2016) Tips and Tactics: Crown rot in winter cereals—Southern region.

55 DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

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, can be particularly effective, as these help to maintain a moist soil surface, which further promotes 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 decay of residue. However, it also spreads infected residue, which may increase plant infection rates in following crops, thus counteracting any benefits from increased rate of breakdown.

Baling, grazing and/or burning crop residues are not effective solutions for the removal of crown rot, either. 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 survive in below-ground tissue even if above-ground material is removed.

Variety selection

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.

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 of disease, the grower can take a calculated risk about 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.

NSW DPI trials at 23 sites in 2013–14 indicate that susceptibility can represent a yield benefit of around 0.50 t/ha in the presence of high levels of crown rot infection. 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. [56]

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 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.

Cultivation

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 the 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

VIDEOS

WATCH: GRDC, Grains research updates: Crown rot tolerance in new cereal cultivars

MORE INFORMATION

Tips and Tactics: Crown rot in winter cereals, southern region

Understanding crown rot underpins effective management, southern and western regions

56 S Simpfendorfer (2015) Crown rot: an update on latest research. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Crown-rot-an-update-on-latest-research

ground. However, cultivation also dries out the soil in the cultivation layer, which immediately slows down decomposition. Decomposition of cereal stubbles is a very slow process that requires adequate moisture for an extended period of time to occur completely. One summer fallow, even if extremely wet and stubble has been cultivated, is *not* long enough!

- Infection—the cultivation of winter cereal stubble harbouring the crown-rot fungus breaks the inoculum into smaller pieces and spreads them more evenly through the cultivation layer across the paddock. Consequently, the fungus is given a much greater chance of coming into contact with seedlings when the next winter cereal crop germinates and starts to grow. 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 sheaths at the soil surface, thus greatly reducing infection. Cultivation or harrowing negates the option of inter-row sowing as a crown rot management strategy.
- 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 (e.g. macropores). 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 the expression of crown rot late in the season.

Stubble burning

As stubble burning removes the above-ground portion of crown rot inoculum but the fungus will still survive in infected crown tissue below ground, burning is **NOT** a quick fix for high-inoculum situations. The removal of stubble by burning increases evaporation from the soil surface and makes fallow less efficient. A 'cooler' autumn burn is preferable to an earlier hotter burn as it minimises the loss of soil moisture while still reducing inoculum levels.

Reducing water loss

Inoculum level is important in limiting the potential for yield loss from crown rot, but the factor that most dictates the extent of yield loss is moisture and temperature stress during grainfill. Any management strategy that limits the 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 grainfill and exacerbate the impact of crown rot.

Grass-weed management

Grass weeds should be controlled in fallows and in crops, 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.

Sowing time

Earlier sowing within the recommended window for a given variety and region can bring the grainfill period forward and reduce the probability of moisture and temperature stress during grainfill. Earlier sowing can increase root length and depth and provide greater access to deeper soil water later in the season, which buffers against the expression of crown rot. This has been shown in NSW DPI research across seasons to reduce yield loss from crown rot. However, earlier sowing 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 from NSW DPI trial work is the additional detrimental impact of later sowing on grain size in the presence of crown rot infection.

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 sheaths 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 conducted by NSW DPI has also demonstrated the benefits of row placement in combination with crop rotation and the placement of break crop rows and winter cereal rows in the sequence to limit disease and maximise yield. Sowing break crops between standing rows, which are kept intact, then sowing the following cereal crop directly over the row of the previous year's break crop, ensures four years between wheat rows being sown in the same row space. This substantially reduces the incidence of crown rot in cereal crops, improves establishment of break crops (especially canola), and chickpeas will benefit from reduced incidence of virus in standing stubble.

Soil type

The soil type does not directly affect the survival or infection phases of crown rot. However, the water-holding capacity of each soil type does affect the expression of crown rot by the degree to which it buffers triticale plants against moisture stress late in the season. Hence, yield loss can be worse on red soils than black soils due to the generally lower water-holding capacity of red soils. On top of this, other sub-soil constraints, e.g. sodicity, salinity or shallower soil depth, can also reduce the level of plant-available water, which can increase the expression of crown rot. [57]

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 varieties, and for assessing the risk after a non-cereal crop. [58]

MORE INFORMATION

PreDicta B

PreDicta B has been developed for broadacre cropping regions in Australia and includes tests for:

- cereal cyst nematode (CCN)
- take-all
- Rhizoctonia barepatch
- crown rot
- root-lesion nematode
- stem nematode

PreDicta B samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program. The test is not intended for in-crop diagnosis. That is best achieved by sending samples of affected plants to your local plant pathology laboratory. In order to get an accurate result, it is important to follow the PreDicta B sampling protocol precisely (Photo 17). [59]

VIDEOS

WATCH: GRDC, Grains research updates: Improving PreDicta B

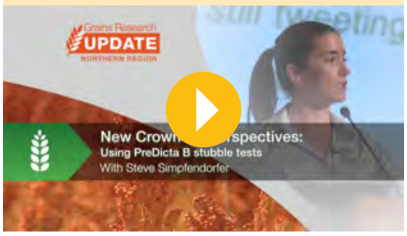


Photo 17: *It is important to follow the PreDicta B sampling protocol precisely.*

Source: GRDC.

57 S Simpfendorfer (2015) Crown rot: an update on latest research. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Crown-rot-an-update-on-latest-research

58 Soilquality.org (2016) Crown rot: Qld. Factsheet, Soilquality.org, http://www.soilquality.org.au/factsheets/crown-rot-queensland

59 D Lush (2014) PreDicta B sampling strategy. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2014/04/PreDicta-B-sampling-strategy

9.7 Common root rot

Common root rot (*Bipolaris*) is a soil-borne fungal disease that 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 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.

One set of trials conducted by SARDI in the SA Mallee found that cereal rye increased *Bipolaris* inoculum levels in a paddock far greater than in volunteer pasture. Bipolaris inoculum levels at the Wynarka site after Bevy rye averaged 88 pgDNA/g in December compared to 18 pgDNA/g following the volunteer pasture. By seeding time these levels had grown to an average 163 pgDNA/g after the Bevy rye, and only 35pgDNA/g after volunteer pasture across 32 soil tests. As the wheat crop ripened in mid-October white heads marked the cereal rye strips, resulting in a 33% yield loss compared to the volunteer pasture (Photo 18). Generally cereal rye is an important break crop in the Mallee to improve soil health, and bipolaris is generally not a strong consideration when planning rotations. This problem was unexpected and suggests further work is needed in this area. [60]

MORE INFORMATION

No-till into pasture, SA Mallee.

Photo 18: *Crop after volunteer pasture (left) and crop after Bevy rye pasture (right) showing white heads in wheat and leading to ~30% yield loss.*

Source: PIRSA

9.7.1 Damage caused by disease

Common root rot can cause yield losses of between 10–15% in susceptible varieties.

9.7.2 Symptoms

Paddock

- Affected plants tend to be scattered over a paddock, and they may be slightly stunted, have fewer tillers and produce smaller heads.
- There may be no distinct paddock symptoms, although the crop may lack vigour.

Plant

- Browning of roots and sub-crown internode (the piece of stem emerging from the seed to the crown) (Photo 19).
- Blackening of sub-crown internode in extreme cases.

60 C McDonough (2014) No-till into pasture, SA Mallee, http://23ha8gmx47t1jcm5w1sd58s7.wpengine.netdna-cdn.com/wp-content/uploads/2014/11/2012-62.-No-till-into-pasture-SA-Mallee.pdf

Photo 19: *Blackening of sub-crown internode in extreme cases.*

Source: SARDI in DAFWA

9.7.3 Conditions favouring development

Key points:

- Can occur from tillering onwards, but most obvious after flowering.
- Appears more prevalent in paddocks that are nitrogen (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.
- The disease can be 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. [61]
- Infection is favoured by high soil moisture for six to eight weeks after planting.

9.7.4 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. [62]

Strategies for management:

61 K Moore, B Manning, S Simpfendorfer, A Verrell. 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

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

- Reduce levels of the fungus in your paddocks by rotating with crops such as field pea, faba bean and canola.
- 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. [63]

9.8 Smut

9.8.1 Bunt or stinking smut

This disease affects mature 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 20). Bunt is usually only noticed at harvest when bunt balls and fragments are seen in the grain. Grain deliveries with traces of bunt balls are unlikely to be accepted at receival.

Photo 20: *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.

63 K Moore, B Manning, S Simpfendorfer, A Verrell. 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

- 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. [64]

9.8.2 Loose smut

Loose smut is a fungal disease that becomes evident at head emergence. A loose, powdery mass of fungal spores is formed in the head; these spores are readily blown away leaving a bare, ragged stalk (Photo 21).

Photo 21: *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. [65]

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. [66]

64 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

65 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

66 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

9.9 Rhizoctonia root rot

Key points:

- 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'.
- 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 in light soils in recent years following the introduction of minimum tillage practices. The previous practice of tillage prior to seeding encouraged the breakdown of the fungus (*Rhizoctonia solani* Kuhn) 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 are least susceptible. Bare patch and root rot of cereals, and damping off and hypocotyl rot of oilseed and legumes are all caused by differing strains of *R. solani*. [67]

In a trial in the SA Mallee, cereal rye was found to decrease levels of Rhizoctonia in a paddock from 43 pgDNA/g in December to 12 pgDNA/g in May. [68]

Rhizoctonia solani inoculum DNA levels were highest at late anthesis within the rotation crops. Inoculum levels were higher in wheat and cereal rye crops compared to that in non-cereal crops. Although cereal rye plants did not show visible Rhizoctonia damage above ground, the pathogen inoculum levels in the soils were similar to that in wheat. [69]

MORE INFORMATION

Karoonda break crops trails—soil biology and rhizoctonia disease.

9.9.1 Symptoms

The characteristic symptom of *Rhizoctonia* is clearly defined bare patches in the crop (figure 1). 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. [70]

VIDEOS

WATCH: Over the Fence: Improving soil health helps fight against rhizoctonia.

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.

67 Soilquality.org (2016) Rhizoctonia—NSW, http://www.soilquality.org.au/factsheets/rhizoctonia-nsw

68 C McDonough (2014) No-till into pasture, SA Mallee, http://23ha8gmx47t1jcm5w1sd58s7.wpengine.netdna-cdn.com/wp-content/uploads/2014/11/2012-62.-No-till-into-pasture-SA-Mallee.pdf

69 V Gupta, S Kroker, D Smith, B Davoren, R Llewellyn, A Whitbread A (2011) Karoonda break crops trails—soil biology and rhyzoctonia disease, https://publications.csiro.au/rpr/download?pid=csiro:EP111477&dsid=DS3

70 Soilquality.org (2016) Rhizoctonia—NSW, http://www.soilquality.org.au/factsheets/rhizoctonia-nsw

- Patches of uneven growth occur from mid-winter when seminal roots have established (Photo 22).

Photo 22: *Patches vary in size from less than a metre to several metres in diameter. Stunted plants occur in patches with a distance edge between diseased and healthy plants.*

Source: DAFWA

Plant

- Affected plants are stunted with stiff, rolled leaves and are sometimes darker green than healthy plants (Photo 23).
- Roots of affected plants are short with characteristic pinched ends: 'spear tips' (Photo 24).

Photo 23: *Affected plants are stunted with stiff, rolled leaves that are sometimes darker than those of healthy plants.*

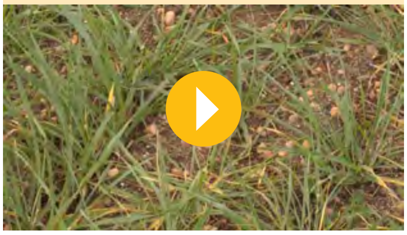
Source: DAFWA

Photo 24: *Roots of affected plants are short with characteristic pinched ends or "spear tips".*

Source: DAFWA

VIDEOS

WATCH: How to diagnose Rhizoctonia root rot.



9.9.2 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. 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. Rhizoctonia appears worse in crops emerging in dry cold growing conditions in light textured low nutrient soils.

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. [71] Ensure soil Zinc levels are adequate or apply foliar zinc to help alleviate Group B herbicide effects.

9.9.3 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 a number of products on the market with claims for Rhizoctonia barepatch control. Consult your local adviser 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. [72]

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.

- 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.

71 Soilquality.org (2016) Rhizoctonia—NSW, http://www.soilquality.org.au/factsheets/rhizoctonia-nsw

72 Soilquality.org (2016) Rhizoctonia—NSW, http://www.soilquality.org.au/factsheets/rhizoctonia-nsw

- 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.
- 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 4).

Table 4: *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	Folicur®	F and S
	Flutriafol	Impact®	F and IF
3 - DMI	Tebuconazole + flutriafol	Impact® Topguard	F
	Tebuconazole + prothioconazole	Prosaro®	F
	Epoxiconazole	Opus®	F
	Triadimenol	Baytan®	S
	Fluquinconazole	Jockey®	S
3 + 11 (Strobilurins)	Azoxystrobin + cyproconazole	Amistar® Xtra	F
	Pyraclostrobin + epoxiconazole	Opera®	F

Source: R Oliver, Curtin University. In GRDC

VIDEOS

WATCH: GCTV9: Banding Fungicide in Cereals.

9.10.1 Fungicide stewardship

A number of pathogens, such as Septoria tritici blotch, 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. [73]

MORE INFORMATION

GRDC Cereal Fungicides Factsheet.

Crop diseases after drought.

9.11 Disease following extreme weather events

9.11.1 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.

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. [74]

9.11.2 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 25),

73 A Milgate (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

74 G Murray, T Hind-Lanoiselet, K Moore, S Simpfendorfer, J Edwards (2006) Crop diseases after drought. Primefacts 408. NSW DPI, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/123718/crop-diseases-after-drought.pdf

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. [75]

Photo 25: *Tan spot infected stubble following flood.*

Photo: Rachel Bowman. Source: Seedbed Media

75 DAFF (2013) Winter cereals pathology. Department of Agriculture, Fisheries and Forestry Queensland, https://www.daf.qld.gov.au/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 nitrogen (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 physiological processes within a plant. They include many agricultural and horticultural chemicals that influence plant growth and development. PGRs are intended to accelerate or retard the rate of growth or maturation, or otherwise alter the behaviour of plants or their produce. [2] This influence can be positive, e.g. larger fruit or more pasture growth, or negative, e.g. shorter stems or smaller plant canopies. [3]

The use of PGR products in Australia has generally been relatively low. The principle reason for this is simply that crop responses are viewed as variable, and growers have not seen enough benefit in incorporating them into their cropping programs.

The most widely used PGRs in Australia 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 with the intention of reducing excessive growth in irrigated broadacre crops. Currently, there are four broad groups of PGRs in use in Australian crops. They are:

1. Ethephon, e.g. Ethrel®.
2. Onium-type PGRs, e.g. Cycocel®, the active ingredient of which is chlormequat (and Pix®, which is registered only for cotton).
3. Triazoles, e.g. propiconazole (which is registered as a fungicide, and not for use as a PGR).
4. Trinexapac-ethyl, e.g. Moddus®, Moddus® Evo.

The four groups of PGRs act by reducing plant cell expansion, resulting in, among other things, shorter and possibly thicker stems. If the stems are stronger and shorter, the crop is less likely to lodge.

1 G McMullen (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 PG Lemaux (1999) Plant growth regulators and biotechnology. Presentation, Western Plant Growth Regulator Society, http://ucbiotech.org/resources/biotech/talks/misc/regulat.html

3 D Jones (2014) Plant growth regulators. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators

Ethephon is applied from the stage of the flag leaf emerging (Z37) to booting (Z45), and reduces stem elongation through the increase in concentration of ethylene gas in the expanding cells.

The PGRs in groups two to four reduce crop height by reducing the effect of the plant hormone gibberellin. These are applied at early stem elongation (Z30–32).

The manufacturers of these products claim other benefits, too, including:

- Better root development that allows for increased root anchorage.
- Better root development that provides greater opportunity for water and nutrient scavenging.
- Possible improved grain quality.
- Reduction in shedding in barley.
- Increased harvest index (HI), the ratio between grain and total dry matter.
- Faster harvest speeds and reduced stress at harvest.

A combination of trinexapac-ethyl and chlormequat applied at growth stage 31 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. [4] Overseas, chlormequat chloride has been found to inhibit gibberellin production, and has been recommended in winter and spring rye, wheat, oats, triticale and winter barley. [5]

Moddus® is registered for ryegrass seed crops, poppies and sugar cane. Moddus Evo®, an enhanced dispersion concentrate of Moddus®, is not currently registered but has been submitted to the Australian Pesticides and Veterinary Medicines Authority (APVMA) for registration to be used in Australian cereals.

An alternative to the chemical PGRs is grazing. It was demonstrated in the Grain and Graze project, which had study sites at a number of mixed-farming locations, that grazed treatments were regularly shorter than the non-grazed treatments, and grazed crops were less prone to lodging. [6]

MORE INFORMATION

Plant growth regulators

Plant growth regulators in broad acre crops

Plant growth regulators and their agronomic and economic benefits to high yield potential cereal, pulse and oilseed crops

10.1.1 Considering mixed results

In Australia, there have been mixed results in the ability of PGRs to increase yield, and therefore profits.

The most important things to remember about PGRs are:

- 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.
- Plant growth regulators must be applied at the correct crop growth stage, according to product directions, which may be well before any lodging issues become apparent.

Photo 1: *Severe lodging of a cereal crop (left).*

Source: Syngenta

4 W Long (2005) AC0003: Plant growth regulators and their agronomic and economic benefits to high yield potential cereal, pulse and oilseed crops. Final Report. Project ACC00003. GRDC, http://finalreports.grdc.com.au/ACC00003

5 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

6 D Jones (2014) Plant growth regulators. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators

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 is considered one of the biggest barriers to reliably achieving high yields in intensive cereal production in Australia. It can result in reduced yields and a difficult harvest. Plant growth regulators have been used for many years, but results can be variable, even having negative effects on yield. The ICC conducted trials in 2003 and 2004 in which there was some reduction in lodging but little yield gain. At the same time, trials on nitrogen (N) management in cereals demonstrated that, to achieve high yields, crops do not necessarily need to be sown at heavy rates and with large amounts of nitrogen, which give a correspondingly lush crop early in the season, but one that is prone to lodging. This has seen many growers adopt a topdressing tactic 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 that yields 8 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 heavily 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.

Conclusions: The value of PGRs

PGRs may have a place in the management of high-yielding crops. Unfortunately, their effects are not consistent and the decision whether to apply a PGR has to be made at approximately three months before the lodging would be expected.

Other chemicals that have a PGR effect are available but are not yet registered for use on all crops or at rates and timings that would have a regulatory effect on growth.

The yield improvements seen in barley in the ICC trials need further investigation, as the reason behind the yield increase is not clear. [7]

MORE INFORMATION

Mixed bag: dual purpose crops, PGRs and other local research

10.1.2 Case study: using Moddus® Evo

Key points:

- Moddus® Evo reduces lodging and can increase yields.
- Application, timing and concentration are critical.
- Moddus® Evo should not be applied to stressed plants.
- Moddus® Evo has better formulation stability and plant uptake

Lodging is considered one of the biggest barriers to reliably achieving high yields in intensive cereal production in Australia. Cereal rye can be prone to lodging. 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 number of other countries, including New Zealand, UK and Germany, to reduce the incidence and severity of lodging and to optimise the yield and quality of high-yielding cereal crops. Moddus® Evo is a formulation with an enhanced dispersion concentrate (DC) 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 before the APVMA for registration for use in Australian cereals.

7 D Jones (2014) Plant growth regulators. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators

GRDC and Syngenta, the manufacturer of Moddus®, undertook research to investigate the value of Moddus® applications to Australian cereals to reduce lodging and improve yields. [8]

Methods

The researchers conducted field trials across Australia from 2004 to 2011. They used a number of varieties, climatic conditions and geographical locations. They established small plots, typically 20–120 m^2 using a randomised complete block design, and incorporating three to six replicates.

They measured the effect of Moddus® application on plant growth, stem strength, stem-wall thickness, lodging, lodging score, and yield, and took grain-quality measurements.

Results

In the trials, overall improvements in yield were often correlated with a reduction in stem height, irrespective of whether lodging had occurred. 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, a few trials gave anomalous results, in which the application of Moddus® Evo did not improve yield. When the researchers examined these trials, they found that either environmental conditions during the lead-up to the application of the chemical were poor—with extensive frosting, drought, poor subsoil moisture—or there were nutrient deficiencies in the crop. As a result, they recommended that Moddus® Evo should only be applied to healthy crops with optimum yield potential. As well, the timing and concentration of Moddus® Evo applications is critical to produce the optimal yield improvements.

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.

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 N.
- 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 N 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

8 LM Forsyth and K McKee (2013) Moddus Evo: controlling plant growth for reduced lodging and improved cereal yields. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Moddus-Evo-Controlling-plant-growth-for-reduced-lodging-and-improved-cereal-yields

9 GRDC (2009) Canopy management factsheet, https://grdc.com.au/uploads/documents/GRDC_CanopyManagement_4pp.pdf

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 is 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 grainfilling 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 11 June Gnarwarre (Geelong region), Victoria (in high rainfall zone) region treated with same level of N.*

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.

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.

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

10 G McMullen (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://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

- 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 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]

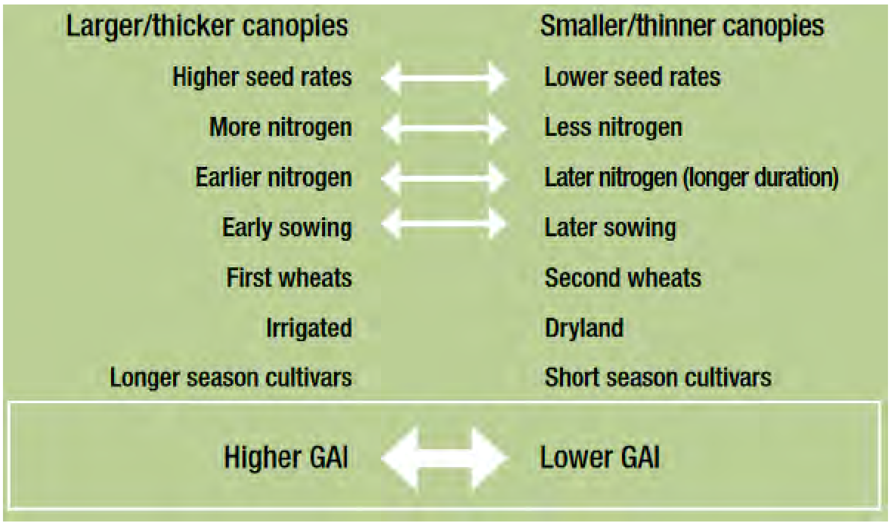


Figure 1: *Factors under grower control that influence canopy density, size and duration.*

NOTE: GAI = Green area index (amount of green surface area).

Source: GRDC

While N timing and rate are key components of successful canopy management, it is essential that they be considered in conjunction with the inter-related factors of:

- soil moisture;
- soil N 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.

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/uploads/documents/GRDC_CanopyManagement_4pp.pdf

IN FOCUS

Canopy management—Inverleigh

Trials to inform canopy management guidelines were conducted in Inverleigh, Victoria, in 2007. Barley was sown on June 13th following canola stubble. With high soil N reserves (203 kg/ha N, 0 = 90 cm) recorded at sowing, there was a small but significant response to applied N (0.21 t/ha at 50 kg/ha N and 0.23 t/ha at 100 kg/ha N) (Figure 2). There was a significant advantage to N timed during stem elongation (GS31–33) over N applied in the seedbed (Figure 3).

There was a non-significant trend for the higher populations (193 plants/m^2) to be higher yielding than 100 plants/m^2 (0.21 t/ha mean advantage), with the highest yields in the trial recorded when the higher plant population was combined with GS31–33 N timings. At 50 kg/ha N these timings produced malting grade qualities with the exception of test weight, which was below 65 kg/ha in all treatments in the trial.

The best margins (after N and seed costs had been deducted) came from 190 plants/m^2 with N timed at GS31–33 at 50 kg/ha N. Interestingly, there was a greater response to 100 kg/ha N over 50 kg/ha N with the thinner crop canopy, leading to a significant interaction between N rate and plant population. However, higher plant populations with 50 kg/ha N still produced better margins. This may have to a need to boost tillers in the lower plant population but not in the higher population. [14]

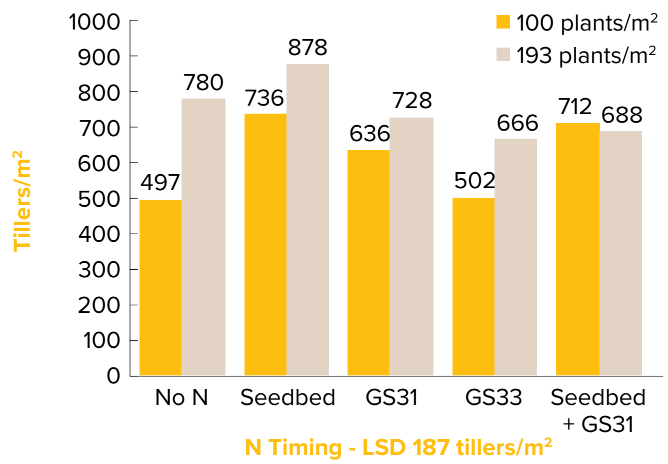


Figure 2: *Influence of different N timings and plant population on tiller/m^2.*

Source: Online farm trials

14 N Poole (2007) Defining guidelines for canopy management in Barley for different climatic regions of Australia—June sown Gairdner—Inverleigh, VIC, http://www.farmtrials.com.au/trial/15841

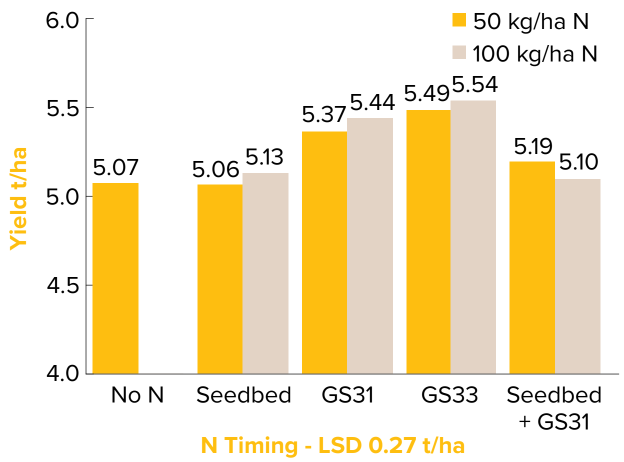


Figure 3: *Influence of different N timings and rates (mean of both plant populations) on yield (t/ha).*

Source: Online farm trials

10.2.1 Cereal Canopy management in a nutshell

1. Select a target head density for your environment (350–400 heads/m² 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/m² would cover most scenarios.
4. Lower end of range (80–100 plants/m²): earlier sowings/high fertility and or low yield potential low-rainfall environments.
5. Higher end of the range (150–200 plants/m²): 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:
   a. maximise potential grain size and grain number per head;
   b. maximise transpiration efficiency;
   c. ensure complete radiation interception from when the flag leaf has emerged (GS39); and
   d. 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 and can be employed where tiller numbers and soil N seems deficient for desired head number. Conversely, where tiller numbers are high and crops are still regarded as too thick, N can be delayed further until the second or third node (GS32–33), which will result in less tillers surviving to produce a head. Much of the research on topdressing N has focused on the role of in-crop N to respond to seasons in which yield potentials have increased significantly due to above-average rainfall conditions.

In these situations, research has shown that positive responses can be achieved, especially when good rainfall is received after N application. [15]

10.2.2 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 N at seeding.

Boosting tiller numbers with seeding N results in greater tiller loss between stem elongation and grain fill. This specifically occurs in two situations: low rainfall, short-season 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 N reserve and region, is the basis for setting up the crop canopy.

10.2.3 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 N 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 N is limited, in many cases the best canopy management is not to apply inputs such as N 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 N 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.

10.2.4 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 N reserves provide much more flexibility in managing the canopy with tactical N applied during stem elongation.

Timing of deep-soil tests is important. Deep-soil N tests carried out in summer, several months before seeding may reveal less soil N 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 N reserves and the justification for N application at this stage.

15 GRDC (2014) Advancing the management of crop canopies, http://www.grdc.com.au/CanopyManagementGuide

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 3). [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/ m^2—N-rich (left) and 266 tillers/m^2 (right).*

Source: GRDC

A useful guide that requires no sophisticated equipment is to apply an excess of N at sowing, for example 50–100 kg N/ha, to a small area of the paddock, approximately 2 m x 10 m.

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 N 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.

10.2.5 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

- Increased interest in no-till farming has created a trend for wider crop row spacing (Figure 4).

16 GRDC (2009) Canopy management Factsheet, https://grdc.com.au/uploads/documents/GRDC_CanopyManagement_4pp.pdf

- 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]

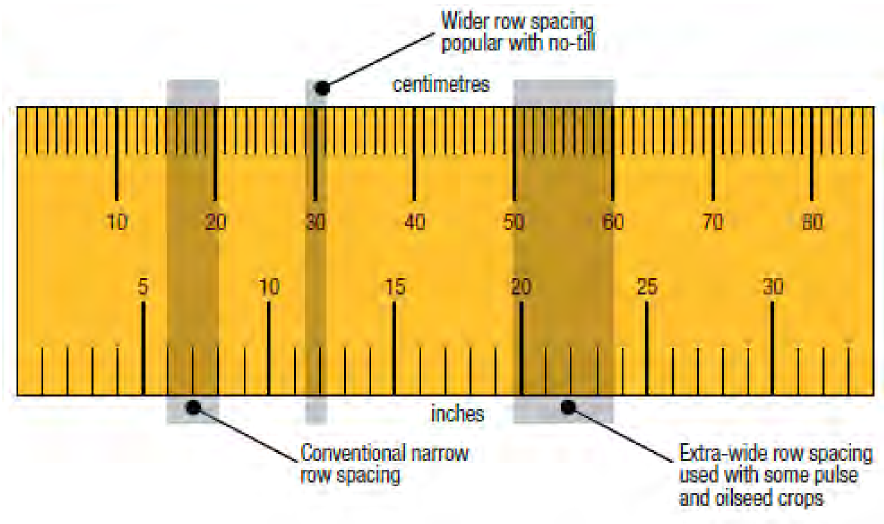


Figure 4: *Common row spacings in metric and imperial measurements.*

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]

17 GRDC (2011) Crop placement and row spacing factsheet—Southern region. https://grdc.com.au/uploads/documents/GRDC_FS_CropPlacement_South.pdf

18 GRDC (2014) Advancing the management of crop canopies, https://grdc.com.au/Resources/Publications/2014/01/Advancing-the-management-of-crop-canopies

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

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/m^2 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 (kg/h) 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

N 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 N efficiency observed with stem elongation applied N

19 GRDC (2014) Advancing the management of crop canopies, https://grdc.com.au/Resources/Publications/2014/01/Advancing-the-management-of-crop-canopies

20 GRDC (2014) Advancing the management of crop canopies, https://grdc.com.au/Resources/Publications/2014/01/Advancing-the-management-of-crop-canopies

21 GRDC (2014) Advancing the management of crop canopies, https://grdc.com.au/Resources/Publications/2014/01/Advancing-the-management-of-crop-canopies

was more important with narrow row spacing since higher yields lead to a tendency for lower protein. [22]

10.2.6 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 GS25–31 in order to take advantage of rainfall. Even applications delayed until flag leaf, can be successful where starting soil N is not too low (Figure 5).

Results from winter wheat cropping trials across Australia on the use of in-crop solid N at stem elongation show that where soil N 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 (2006–08) have limited the results produced from trials. These trials assessed stem elongation N use in cereals grown on wider-row spacings 300–350 mm compared to 175–200 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% in the high rainfall zone. [23]

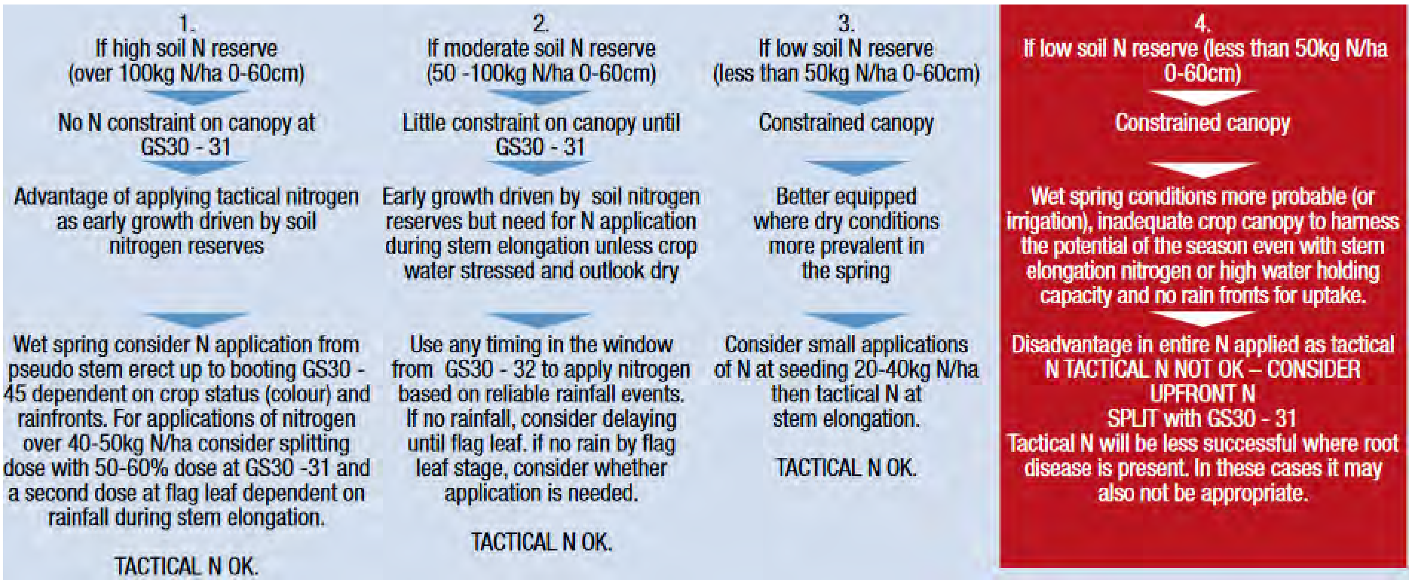


Figure 5: *Broad scenarios based on soil N level.*

Source: GRDC

10.2.7 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.

22 GRDC (2014) Advancing the management of crop canopies, https://grdc.com.au/Resources/Publications/2014/01/Advancing-the-management-of-crop-canopies

23 GRDC (2009) Canopy management Factsheet, https://grdc.com.au/uploads/documents/GRDC_CanopyManagement_4pp.pdf

MORE INFORMATION

Canopy management factsheet

Cereal growth stages guide

Advancing the management of crop canopies.

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. [24]

24 McMullen G. (2009) Canopy management in the Northern Grains region. 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

Crop desiccation/spray out

Not applicable for this crop.

Harvest

Key messages

- Rye is ready to harvest when the leaves are dead and the stems have turned yellow-brown in colour. [1]
- Rye is susceptible to head shatter, which makes it difficult to harvest and results in many volunteer plants emerging in the field next season (Photo 1). [2]
- Because cereal rye matures earlier than other small grains, strict harvest and grazing management procedures are important to prevent it from becoming a weed.
- The limited information available on cereal rye suggests that the preferred growth stage to harvest for silage is the boot stage. Feed quality of cereal rye deteriorates more quickly with maturity compared to other cereals. [3]
- Ensure that all equipment is clean and work to avoid blockages so that fire risk can be minimised.

Although rye comes into ear earlier than wheat, the grain takes much longer to mature. Rye is ready to harvest when the leaves are dead and the stems have turned yellow-brown [4], and the crop should be harvested as soon as the grain is thoroughly dry and hard. Seed losses due to shattering can occur soon after it ripens. Rye is harvested with a conventional header. The grain is slightly lighter and longer than wheat, so the machine will require minor adjustments from normal wheat settings. [5] The grain threshes very easily. Under dry threshing conditions care must be taken to adjust the concave setting and/or cylinder speed to minimise cracking. [6]

Photo 1: *Seed head shatter in mature rye. About ¾ of the head has broken off and fallen to the ground.*

Source: Homegrown Goodness

1 Plant Village. Rye Secale Cereale, https://www.plantvillage.org/en/topics/rye/diseases_and_pests_description_uses_propagation

2 Van Veldhuizen B (2010) Growing small grains in your garden, http://www.uaf.edu/files/snras/C135.pdf

3 DPI NSW. Chapter 5: Crops and by-products for silage. In Successful Silage, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/294053/successful-silage-topfodder.pdf

4 Plant Village (n.d.) Rye *Secale cereale*. Plant Village, https://www.plantvillage.org/en/topics/rye/diseases_and_pests_description_uses_propagation

5 Agriculture Victoria (2013) Growing Cereal Rye, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

6 Alberta Agriculture and Forestry (2016) Fall rye production. Revised. AgDex 117/20-1. Alberta Agriculture and Forestry,

12.1 Windrowing

Windrowing is a practice in high yielding crops to prevent excess shattering of grain. High yielding crops are not common in the Southern growing region except in unusual circumstances, therefore windrowing is not a common practice.

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 windrow 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. [7]

Photo 2: *Directing chaff into a narrow windrow using a custom-made chute.*

Source: GRDC

12.1.1 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.

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

- 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. [8]

12.1.2 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. [9]

12.1.3 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. [10]

MORE INFORMATION

Setting up at harvest for narrow windrow burning

12.2 Harvest timing

Although rye 'heads' much earlier than wheat, it takes much longer to mature its grain, so the harvest of the two crops can clash. The crop should not be harvested until the grain is thoroughly dry and hard, but it should then be harvested immediately as shattering is likely to occur soon after ripening. [11]

Grain is harvested at about the same time as wheat. Harvest as soon as the grain dries and hardens. Ripe crops that are left to stand are likely to shed grain. Maturity is often uneven, so inspect the whole paddock before harvest.

The moisture level in rye should be about 12% at harvest (Photo 3). Only harvest in dry conditions. When harvesting with a combine, growers may need to cut the straw

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

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

10 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

11 RL Reid (Ed.) (2013) The manual of Australian agriculture. Elsevier.

high in order to avoid clogging the equipment, since rye is tall and produces a large quantity of straw. This will obviously leave taller stubble in the paddock. [12]

Photo 3: *Rye ripening.*

Source: PlantVillage

MORE INFORMATION

GRDC Grain Storage Fact Sheet: Hygiene and Structural Treatment for Grain Storages.

12.2.1 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 allow crop to better feed into harvester front, ensuring less difficulty in the harvest operation and minimal losses. [13]

12.2.2 Harvesting for silage

Cereals suitable for ensiling are oats, barley, wheat, triticale and cereal rye. The limited information available on cereal rye suggests that the preferred growth stage to harvest for silage is the boot stage. Feed quality of cereal rye deteriorates more quickly with maturity compared to other cereals. [14]

Hay

When harvesting rye for hay, it has been found that delaying harvest until three weeks after rye has flowered results in losses of approximately 50% in the crude protein and only slight gain in total yield. For the best hay quality and near maximum yields, harvest rye while in flower. [15]

When to cut for silage

The timing of harvest should take into consideration the following:

- End use of the silage; i.e. for animal production versus maintenance rations.

12 UVM Extension Crops and Soils Team. Cereal Rye, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

13 Agriculture Victoria (2008) Harvesting Forage Cereals, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/harvesting-forage-cereals

14 DPI NSW. Chapter 5: Crops and by-products for silage. In Successful Silage, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/294053/successful-silage-topfodder.pdf

15 F Sneva, D Hyder (1963) Raising dryland Rye hay, http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/15547/StationBulletin592.pdf;jsessionid=01647E0066F56EBD1CE909A02C046403?sequence=1

- Weather conditions at harvest.
- Soil types and soil moisture conditions at harvest.
- If double cropping, when the following crop needs to be sown.
- Availability of suitable harvesting machinery.

Harvesting at the correct DM content is important to ensure optimal yield, minimal loss of nutritive value and a desirable fermentation process.

Cereals can be harvested at the flag leaf/boot to early ear emergence stages or the soft dough stage.

One study found that delaying harvest until three weeks after rye had flowered resulted in:

- losses of approximately 50% in the crude protein per acre, and
- only slight gain in total yield.

For the best hay quality and near maximum yields, harvest rye while in flower. [16]

DM levels recommended for ensiling

If cutting at the flag leaf/boot stage, the recommended DM level is in the ranges of 33–40% DM for forage harvested material and 38–50% DM for baled silage. The recommended DM ranges for cutting at the soft dough stage are 35–42% DM for forage harvested material and 38–45% DM for baled silage.

Cereal plants contain large stems, leaves ranging from green (alive) to yellowing (dying) and grain heads in various stages of formation in the latter stages of growth. This makes the estimation of the DM content at which to begin harvesting difficult.

It is essential that a representative sample be obtained for estimating the DM content of the crop.

Mowing

The stage of growth of the crop at harvest will determine whether it is mown and wilted before harvesting or direct cut and ensiled as a "standing" crop. However, the height of cutting can have some implications on the stored product.

Mowing height

Cutting height is usually 7–10 cm above ground level. Cutting higher will result in a slight increase in nutritive value, but reduced yields. Research in Australia and New Zealand has shown that cutting 10 cm higher on a 15 t DM/ha crop will reduce yield by approximately 1 t DM/ha.

If mown and wilted, the higher cutting height will also tend to keep the mown windrow higher off the ground, thereby allowing more airflow under the crop and a slightly faster wilting rate. It will also reduce the risk of soil contamination from other equipment operations such as raking. However, cutting at greater heights will leave behind increased levels of stubble, which creates a problem of removal in the future and preparation for the next forage. [17]

12.2.3 Equipment

Cereal rye is tall, and the bulky straw makes harvest slow due to the large volume going through the harvester. A standard wheat header is suitable for harvesting cereal rye. Adjustments need to be made to the harvester settings to avoid grain losses and damage, because the grain is lighter and longer than wheat. Tall crops

16 F Sneva F, D Hyder (1963) Raising dryland Rye hay, http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/15547/StationBulletin592.pdf;jsessionid=01647E0066F56EBD1CE909A02C046403?sequence=1

17 Agriculture Victoria (2008) Harvesting Forage Cereals, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/harvesting-forage-cereals

are likely to lean or lodge, so crop lifters might be necessary. Clean out all machinery after harvest to prevent other cereal grains becoming contaminated with cereal rye. [18]

Rye is harvested with a conventional header. The grain is lighter and longer than wheat, so the machine will require minor adjustments from normal wheat settings. [19]

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 winter cereals.

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 swathe.

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 at 30 cm. A rule of thumb is a 10% efficiency increase for every 10 cm of harvest height. If a 100 ha 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 4).

Photo 4: *Cereal harvest underway. It is important to clean all equipment prior to and after harvesting.*

Source: Creative Commons (Wikimedia)

Forage harvesters

Whole-crop cereals should ideally be harvested using a precision chopping forage harvester to ensure a short chop length (20–50 mm actual length). This ensures the material can be well compacted in the stack or pit, minimising the amount of air

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

19 Agriculture Victoria (2013) Growing Cereal Rye, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

20 A Lawson (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

trapped and resulting in reduced losses (nutritive value and DM). Losses are due to continued plant and microbial respiration during the early phases of fermentation.

Most other forage harvesting machines, such as self-loading wagons, cut the material to varying lengths, often over 200 mm, making adequate compaction very difficult.

The drier the crop DM content at harvest, the shorter the chop length required. Chopping the material short also ensures a thorough mixing of the high nutritive heads with the much lower nutritive stems and leaves.

Increased density also reduces the rate of aerobic spoilage at stack opening, a common although not insurmountable problem with cereal silages. Less wastage also occurs as animals cannot easily select the heads and leave the stem material when fed.

Increasingly, forage cereals are being direct-harvested at the later growth stage with forage harvesters that have a cutterbar instead of the typical rotary disc mowers, to reduce grain loss. Grain loss from the gaps in the housing of the chopping and feeding mechanisms can be minimised by fitting blanking plates.

Due to the rotary disc action of the mower, particularly if raked before harvesting, grain loss may be slightly higher in pre-mown crops. DM yield and nutritive value will also be slightly lower.

If the crop is harvested after the soft dough stage, the grain will be hardening as it matures. Forage harvesters, which are fitted with specific rollers for cracking grain (often referred to as ‘primary processing’) will be essential.

Balers

Harvesting whole-crop using balers is not recommended, as dense compaction is often not achieved and vermin damage to the bales in storage can be a serious problem. If whole-crop cereals are to be harvested with round and square balers, the material needs to be wilted to slightly higher DM contents to ensure a lactic acid fermentation occurs.

Balers with chopping mechanisms are highly recommended to aid compaction. The fermentation process and animal intake of WCS will also benefit substantially from the chopping. Once past the ideal stage for harvesting, cereal stems become more lignified (stiffer) and the stems are hollow, i.e. they contain more air internally. These drier stems will allow increased air to be trapped within and between the stems in the bale. In this situation, a chopping baler, with all knives in operation, is highly recommended. An alternative is to bale at the moister end of the DM range recommended for baling. Baling with some dew on the material will also be useful if DM levels are above those recommended.

Baling at a slower forward speed will also allow most balers to produce a denser bale. Baling material that is too dry, or not tightly compacted, results in large volumes of air being trapped in the bale thus reducing nutritive value and increased risk of puncturing by the stalks.

Anecdotal feedback from some machinery operators indicate that if a mower only is used for the later growth stages of the crop, particularly when baling, the baler should travel in the opposite direction to the mower. The heads of the crop are picked up first which results in much less trouble in the "picking up" and "feeding in" of the forage into the machine. However, one piece of research has indicated that friction from the rolling mechanisms in some balers induces heavier grain loss than that from forage harvesters. More research is needed to determine losses at all stages of WCS harvesting and storage.

Applying netwrap instead of twine will also reduce the amount of air trapped between the plastic and the bale as the twine, especially in slightly loose bales, will "pull" into the bale. This allows air to travel around the twine once plastic is applied, possibly becoming mouldy—particularly if holed. Applying netwrap will also minimise straw stalks protruding from the bales, which can puncture the stretchwrap plastic seal, allowing air to enter. [21]

12.3 Fire prevention

Grain growers must take precautions during the harvest season, as operating machinery in extreme fire conditions is dangerous. They should take all possible measures to minimise the risk of fire. Fires are regularly experienced during harvest in stubble as well as standing crops. The main cause is hot machinery combining with combustible material. This is exacerbated on hot, dry, windy days. Seasonal conditions can also contribute to lower moisture content in grain and therefore a greater risk of fires.

Harvester fire reduction checklist

1. Recognise the big four factors that contribute to fires: relative humidity, ambient temperature, wind and crop type and conditions. Stop harvest when the danger is extreme.
2. Focus on service, maintenance and machine hygiene at harvest on the days more hazardous for fire. Follow systematic preparation and prevention procedures.
3. Use every means possible to avoid the accumulation of flammable material on the manifold, turbocharger or the exhaust system. Be aware of side and tailwinds that can disrupt the radiator fan airblast that normally keeps the exhaust area clean.
4. Be on the lookout for places where chaffing can occur, such as fuel lines, battery cables, wiring looms, tyres and drive belts.
5. Avoid overloading electrical circuits. Do not replace a blown fuse with a higher amperage fuse. It is your only protection against wiring damage from shorts and overloading.
6. Periodically check bearings around the harvester front and the machine. Use a hand-held digital heat-measuring gun for temperature diagnostics on bearings and brakes.
7. Maintain fire extinguishers on the harvester and consider adding a water-type extinguisher for residue fires. Keep a well maintained fire fighting unit close-by to the harvesting operation ready to respond.
8. Static will not start a fire but may contribute to dust accumulation. Drag chains or cables may help dissipate electrical charge but are not universally successful in all conditions. There are some machine mounted fire-suppression options on the market.
9. If fitted, use the battery isolation switch when the harvester is parked. Use vermin deterrents in the cab and elsewhere, as vermin chew some types of electrical insulation.
10. Observe the Grassland Fire Danger Index (GFDI) protocol on high fire risk days.
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. [22]

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

21 Agriculture Victoria (2008) Harvesting Forage Cereals, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/harvesting-forage-cereals

22 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

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. [23]

Harvester fire research

With research showing an average of 12 harvesters burnt to the ground every year in Australia (Photo 5), agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses.

Key findings:

- Most harvester fires start in the engine or engine bay.
- Other fires are caused by failed bearings, brakes and electricals, and rock strikes. [24]

Photo 5: *GRDC figures show that there are 1000 combine harvester fires in Australia each year.*

Source: Weekly Times

23 NSW Rural fire Service. Farm firewise. NSW Government, http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161

24 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

PODCAST

MORE INFORMATION

[GRDC Reducing Harvester Fire Risk: The Back Pocket Guide]

[An investigation into harvester fires]

[Plan of attack needed for harvester fires]

[AWB receival standards for Cereal rye in the 2016/2017 season.]

Grain Trade Australia, [Cereal Rye and Triticale trading standards 2015/2016]

[Cereal Rye Standards.]

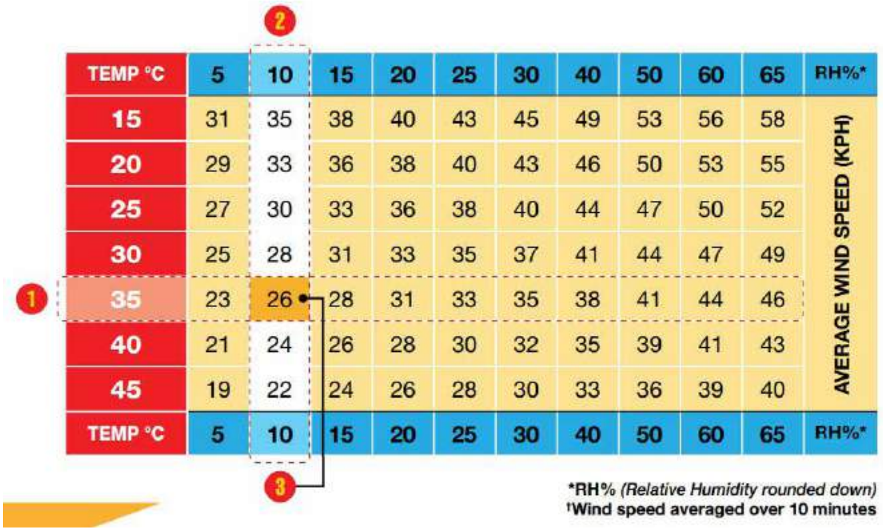
12.3.1 Harvesting in low-risk conditions

Growers can use the Grassland Fire Danger Index guide to assess the wind speed at which harvest must cease (a GFDI of 35), depending on the temperature and relative humidity (Figure 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% 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%*

Figure 1: *Grassland fire danger index guide.*

Source: [CFS South Australia]

12.4 Receival standards

Cereal rye standards for the recent season. These standards are to be applied on individual truck loads and must not be averaged over a number of loads.

Table 1: *Grain Trade Australia recieval standards for cereal rye.*

Category	Standard
Moisture max. (%)	12.0
Description	Clean, sound mature whole grain, amber-light brown colour, free from genetic modification. The seller warrants the rye is fit for human consumption and complies with the standards laid down under the Food Standard Code.
General	Rye tendered for delivery shall be free from any uncharacteristic odours, infestation, objectionable material and any nominated commercially unacceptable contaminant.
Specific Allergens	Nil presence of peanuts or biological material of any kind derived from the peanut plant in rye tendered for delivery.
Chemical treatment	No chemical treatments are to be used on harvested rye unless authorised in writing by Allied Mills, any other chemical treatments must be declared at the time of receival. It is illegal to deliver grains containing above 0.3ppm phosphine.

Source: [Grain Trade]

12.5 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. [25]

Trials in both south-eastern and western Australian grain growing regions have found a 55–58% reduction, overall, in the emergence of annual ryegrass across the three main harvest weed-seed control (HWSC) systems being practiced by growers. [26]

MORE INFORMATION

IWM manual section on harvest weed management.

IWM manual section on narrow windrow burning.

12.5.1 HWSC Strategies

Weed seed capture and control at harvest can assist other tactics to put the weed seed bank into decline. Up to 95% of annual ryegrass seeds that enter the harvester exit in the chaff fraction. If it can be captured, it can be destroyed or removed.

Western Australian farmers and researchers have developed several systems to effectively reduce the return of annual ryegrass and wild radish seed into the seed-bank, and help put weed populations into decline.

A key strategy for all harvest weed seed control operations is to maximise the percent of weed seeds that enter the header. This means harvesting as early as possible before weed seed is shed, and harvesting as low as is practical, e.g. 'beer can height.'

Narrow windrow burning

During traditional whole paddock stubble burning, the very high temperatures needed for weed seed destruction are not sustained long enough to kill most weed seeds. By concentrating harvest residues and weed seed into a narrow windrow, fuel load is increased and the period of high temperatures extends to several minutes, improving the kill of weed seeds.

Windrow burning for weed control—WA fad or a viable option for the east?

- Continued reliance on herbicides alone is not sustainable in our continuous cropping systems. Rotating herbicides alone will not prevent the development of resistance.
- Early implementation of windrow burning will prolong the usefulness of herbicides, not replace them.
- Windrow burning is the cheapest non-chemical technique for managing weed seeds present at harvest.
- Even with higher summer rainfall, windrow burning is a viable option for NSW cropping systems.
- Windrow burning is an effective weed management strategy, even in the absence of resistance.

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25 S Watt (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

26 S Clarry (2015) Trials measure harvest weed-seed control, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

MORE INFORMATION

Windrow burning for weed control – WA fad or a viable option for the east?

IWM manual section on chaff carts

IWM manual section on bale direct systems

- Growers need to begin experimenting now on small areas to gain the experience needed to successfully implement the strategy. [27]

Narrow windrow burning is extremely effective—destroying up to 99% of annual ryegrass and wild radish seeds—but it must be done properly. For ryegrass, a temperature of 400°C for at least 10 seconds is needed to destroy the seeds' viability. For wild radish, the temperature needs to be 500°C for at least 10 seconds. [28]

Chaff Carts

Chaff carts are towed behind headers during harvest to collect the chaff fraction (Photo 6). Collected piles of chaff are then either burnt the following autumn or used as a source of stock feed.

Photo 6: *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. [29]

Bale direct systems

The bale direct system uses a baler attached to the harvester to collect all chaff and straw material. This system requires a large baler to be attached to the back of the harvester. As well as removing weed seeds, the baled material has an economic value as a livestock feed source. (See http://www.glenvar.com/ for the story and development of header-towed bailing systems).

Harrington Seed Destructor

The integrated Harrington Seed Destructor (iHSD) is the invention of Ray Harrington, a progressive farmer from Darkan, WA (Photo 7). Developed as a trail behind unit, the iHSD system comprises a chaff processing cage mill, and chaff and straw delivery systems. The retention of all harvest residues in the field reduces the loss and/or banding of nutrients and maintains all organic matter to protect the soil from wind and

27 M Street, G Shepherd (2013) Windrow burning for weed control—WA fad or a viable option for the east? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Windrow-burning-for-weed-control-WA-fad-or-viable-option-for-the-east

28 S Clarry (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

29 S Clarry (2015) Trials measure harvest weed-seed control, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

MORE INFORMATION

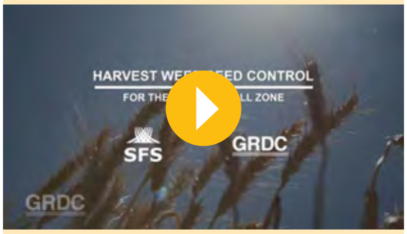
IWM manual section on Harrington seed destructor

Section on the Harrington Seed Destructor in GRDC's Tactics for managing weed populations

Chaff deck concentrates weeds in controlled traffic

VIDEOS

WATCH: Harvest weed seed control for the high rainfall zone.



WATCH: Harvest – the time to get on top of resistant weeds.

WATCH: A beginner's guide to harvest weed seed control.

water erosion, as well as reducing evaporation loss when compared with windrow burning, chaff carts and baling. [30]

The HSD, which renders seeds non-viable by collecting and impacting the chaff as it exits the harvester, can be 92–99% effective, depending on seed species. [31]

Photo 7: *Harrington Seed Destructor at work.*

Source: GRDC

The chaff deck places the chaff exiting the sieves of the harvester on to permanent wheel tracks. Growers using chaff decks have observed that few weeds germinate from the chaff fraction and believe that many weed seeds rot in it. A permanent tramline farming system is necessary to be able to implement the chaff deck system. [32]

30 GRDC Integrated weed management hub. Section 6: Managing weeds at harvest, https://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

31 S Clarry (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

32 Roberts P. (2014). New systems broaden harvest weed control options. GRDC. https://grdc.com.au/Media-Centre/Media-News/West/2014/11/New-systems-broaden-harvest-weed-control-options

Storage

Key messages

- Rye is considered to be dry and safe for storage at 12% or lower kernel moisture. At this moisture content, loss of condition due to moulds or mites is unlikely. [1] However, southern Australian recommendations are to store rye at less than 10% moisture, preferably in sealed silos.
- Rye that is grown for milling and baking needs to meet specified commercial and hygienic standards. Therefore, early harvesting and proper drying before storage are necessary. [2]
- Cereal rye grain does not store well unless frequently treated for insect contamination.
- Seed germination drops rapidly when fall rye is stored longer than a year. [3]
- Moisture content and temperature of the grain during harvest determine the safe storage period. Drying and cooling of freshly harvested, moist, warm grain is an important operation before it is sent into processing or storage.

Drying and storage of cereal rye is similar to wheat. Rye that goes for milling and baking has to meet specified commercial and hygienic standards. Therefore, early harvesting and proper drying before storage are necessary. [4]

Cereal rye grain does not store well unless frequently treated for insect contamination. To minimise insect attack, the grain should be stored at less than 10% moisture, preferably in sealed silos. Treat the grain as it enters the silo and then check regularly (2–3 months) for reinfestation by grain insects. [5]

Rye should have 12% or less moisture content (MC) when stored. Safe storage guidelines for grains at different moisture contents and storage temperatures are essential to know how long seed can be held without deterioration. Moisture content and temperature of the grain during harvest determine the safe storage period. Drying and cooling of freshly harvested, moist, warm grain is an important operation before it goes for processing or storage.

Seed germination drops rapidly when cereal rye is stored longer than a year. [6]

IN FOCUS

Safe storage guidelines for rye.

Safe storage guidelines for grains at different moisture contents and storage temperatures are essential to know how long seed can be held without deterioration. Rye samples with 10.0, 12.5, 15.0, and 17.5% moisture content (wet basis) were stored at 10, 20, 30, and 40°C for 16 weeks. Germination, moisture content, visible and invisible microflora, and free fatty acid (FFA) values were monitored periodically. Germination rate decreased significantly with increase in moisture content, temperature, and storage period. Moisture content of the samples stored at 10°C increased with time, whereas that of samples stored at 30 and 40°C decreased. Visible mold appeared in all the 17.5% moisture samples and in all the samples stored at

1 Alberta Agriculture and Forestry. Harvesting and storing fall rye, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex4460

2 G Sathya, DS Jayas, NDG White (2008), Safe storage guidelines for rye. Canadian Biosystems Engineering, 50(3.1), e3. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.498.6611&rep=rep1&type=pdf

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

4 G Sathya, DS Jayas and NDG White (2008) Safe storage guidelines for rye. Canadian Biosystems Engineering, 50, 3.1–3.8, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.498.6611&rep=rep1&type=pdf

5 Agriculture Victoria (2013) Growing cereal rye, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

6 Alberta Agriculture and Forestry (2016) Fall rye production. Revised. AgDex 117/20-1. Alberta Agriculture and Forestry http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

40°C. *Penicillium spp*. and *Aspergillus glaucus* group were the predominant fungi in almost all samples throughout the study. Fat Acidity Value (FAV) increased with increasing moisture content, temperature, and storage time. Safe storage guidelines with respect to initial moisture content and temperature were developed based on the drop in germination and appearance of visible mold. Rye with <12.5% moisture content stored at <20°C would be safe for at least 15 weeks, whereas rye with >15% moisture content stored at 40°C would have less than a week to complete drying and cooling (Figure 1). [7]

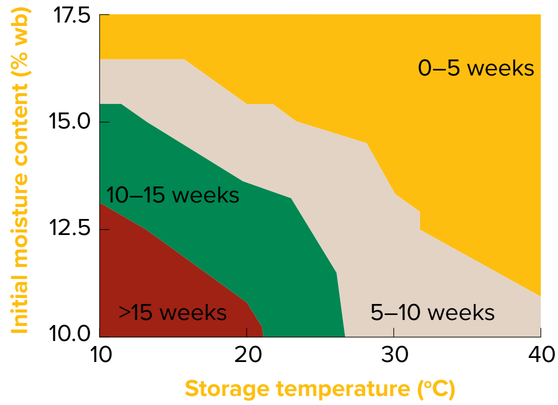


Figure 1: *Estimated safe storage life of rye based on 20% decrease in the initial germination and no visible mould. Periods of safe storage are indicated.* [8]

Source: Canadian Biosystems Engineering

GRDC Stored grain information hub

Following the work already done through the Grain Storage Extension Project, the GRDC have funded another three years allowing grain storage extension to continue through to 2018.

The project aims to provide a stored grain information hub and equip growers with the skills and knowledge to enable best management practices of on-farm grain storage. Some exciting new resources to keep an eye out for under the new project will be an eLearning Manual, a smart phone App and an extension community of practice.

For more information on the grain storage extension project or to arrange a workshop in your area contact a member of the team.

- National Hotline 1800 weevil (1800 933 845)
- QLD and northern NSW, Philip Burrill philip.burrill@daff.qld.gov.au
- Southern NSW, VIC, SA and TAS, Peter Botta pbotta@bigpond.com
- WA, Ben White ben@storedgrain.com.au
- Project coordinator Chris Warrick info@storedgrain.com.au

MORE INFORMATION

Stored grain information hub

7 G Sathya, DS Jayas, NDG White (2008), Safe storage guidelines for rye. Canadian Biosystems Engineering, 50(3.1), e3. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.498.6611&rep=rep1&type=pdf

8 G Sathya, DS Jayas, NDG White (2008), Safe storage guidelines for rye. Canadian Biosystems Engineering, 50(3.1), e3. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.498.6611&rep=rep1&type=pdf

13.1 How to store product on-farm

Growers in the southern region are investing in on-farm storage for a range of reasons. In the eastern states, on-farm storage gives growers options into domestic and export markets, while in South Australia—where the majority of grain goes to bulk handlers—growers tend to set up storage to improve harvest management.

Growers might only plan to store grain on-farm for a short time, but markets can change, so investing in gas-tight sealable structures means you can treat pests reliably and safely and leave your business open to a range of markets.

Growers should approach storage as they would approach purchasing machinery: Growers spend a lot of time researching a header purchase to make sure it is fit-for-purpose. Grain storage can also be a significant investment, and a permanent one, so it pays to have a plan that adds value to your enterprise into the future.

> *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.* [9]

Agronomist's view

On-farm storage—Tasmania

- On-farm storage is becoming a popular option to manage risk on-farm.
- Tasmania has limited storage capacity compared to the mainland.
- Understand the capital cost, along with the further costs of storing grain such as interest, hygiene, in/out loading and opportunity costs.
- What is the best fit for your business? Does it align with your strategy?
- Development in central storage will occur in Tasmania as the industry grows. [10]

On-farm grain storage represents a significant investment. Many farms have older storage facilities that cannot be sealed for grain fumigation purposes, but replacing these facilities with sealable silos may not be an economically viable option.

A mixed storage strategy is a possible solution. The strategy is to purchase a small number of sealable silos and to use them to batch fumigate grain prior to sale.

There are several 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;
- 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-

9 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

10 L Stevens (2016) The grain industry in Tasmania harvest logistics, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/08/The-grain-industry-in-Tasmania-harvest-logistics

benefit analysis template is very useful step in the decision making process to test the viability of grain storage on your farm. [11]

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 atmospheres to control insects Easily aerated with fans Fabricated on-site, or off-site and transported Capacity from 15 t to 3,000 t 25 years or more of service life Simple in-loading and out-loading Easily administered hygiene (cone-based silos particularly) Can be used multiple times in a season	Requires foundation to be constructed Relatively high initial investment required Seals must be maintained regularly Access requires safety equipment and infrastructure Requires and annual test to check gas-tight sealing
Unsealed silo	Easily aerated with fans 7–10% cheaper than sealed silos Capacity from 15 t to 3,000 t Up to 25 year service life Can be used multiple times in a season	Requires foundation to be constructed Silo cannot be used for fumigation Insect control limited to protectants in eastern states and Dryacide® in WA Access requires safety equipment and infrastructure
Grain-storage bags	Low initial cost Can be laid on a prepared pad in the paddock Provide harvest logistics support Can provide segregation options Are ground operated	Requires purchase or lease of loader and unloader Increased risk of damage to grain beyond short-term storage (typically three months) Limited insect control options, with fumigation possible only under specific protocols Requires regular inspection and maintenance, which need to be budgeted for Aeration of grain 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

11 GRDC (2015) Grain storage strategies in the northern region, https://grdc.com.au/Media-Centre/Hot-Topics/Grain-storage-strategies-in-the-northern-region

MORE INFORMATION

Benefits flow from on-farm storage in the Mallee.

Utilise this On-farm storage checklist to optimise grain storage potential.

GRDC Retaining seed factsheet.

VIDEOS

WATCH: Over the Fence: On-farm storage pays in wet harvest.

Storage type	Advantages	Disadvantages
Grain-storage sheds	Can be used for dual purposes 30 years or more of service life Low cost per stored tonne	Aeration systems require specific design Risk of contamination from dual purpose use Difficult to seal for fumigation Vermin control is difficult Limited insect control options without sealing Difficult to unload

Source: Kondinin Group

13.1.1 Silos

Cereal rye grain does not store well unless frequently treated for insect contamination. To minimise insect attack, the grain should be stored at less than 12% MC, preferably in sealed silos (Photo 1). Treat the grain as it enters the silo and then check regularly (2–3 months) for reinfestation by grain insects.

Photo 1: *When using on-farm silos it is important to pressure test all silos, even those that are labeled as "sealed".*

Source: GRDC

Sealed silos offer a more permanent grain storage option than grain storage bags. Depending on the amount of storage required, they will have a higher initial capital cost than grain storage bags and are depreciated over a longer time frame than the machinery required for the grain bags. In a silo grain storage system as stored tonnage increases the capital cost of storage increases.

Potential advantages of using sealed grain silos as a method for grain storage include improved harvest management, reduced harvest stress, reduced harvest freight requirements, minimal insecticide exposure and the opportunity to segregate and blend grain.

Potential disadvantages of using sealed grain silos as a method for grain storage include the initial capital outlay, the outlay required to meet occupational health and

MORE INFORMATION

GRDC Pressure testing sealable silos factsheet

GRDC Silo buyer's guide

VIDEOS

WATCH: Pressure testing sealed silos.

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.

Even if a silo is sold as "sealed" it is not sealed until it is proven gas-tight with a pressure test.

The term "sealed" has been used loosely during the past and in fact some silos may not have been gas-tight from the day they were constructed.

However, even a silo that was gas-tight to the Australian Standard on construction will deteriorate over time, so needs annual maintenance to remain gas-tight.

Why do I need to do a pressure test?

In order to kill grain pests at all stages of their life cycle (egg, larvae, pupae, adult) phosphine gas concentration levels need to reach and remain at 300 parts per million (ppm) for 7 days or 200 ppm for 10 days.

The importance of a gas-tight silo

The Kondinin Group 2009 National Agricultural survey revealed that 85% of respondents had used phosphine at least once during the previous five years, and of those users, 37% had used phosphine every year. A Grains Research and Development Corporation survey during 2010 revealed that only 36% of growers using phosphine applied it correctly, in a gas-tight, sealed silo (Figure 2). 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 3). For effective phosphine fumigation, a minimum of 300 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]

12 J Francis (2006) An analysis of grain storage bags, sealed grain silos and warehousing for storing grain, https://grdc.com.au/uploads/documents/Final%20report%20Grain%20Storage%20Bags%2021%20Jul%20061.pdf

13 P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. GRDC Fact Sheet, September 2010, http://storedgrain.com.au/pressure-testing/

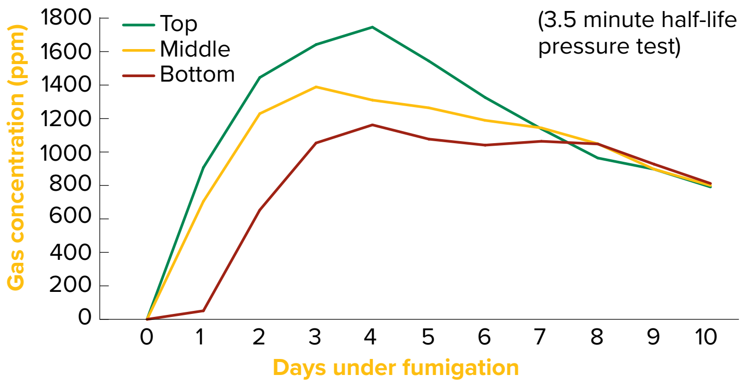
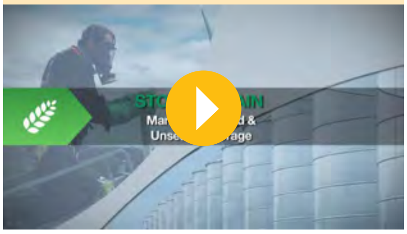


Figure 2: *Gas concentration in gas-tight silo.*

Source: [GRDC]

VIDEOS

WATCH: [Stored grain: Managing sealed and unsealed storage]



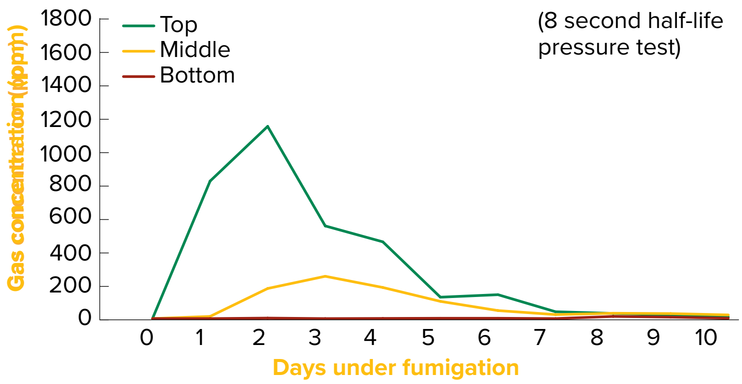


Figure 3: *Gas concentration in non-gas-tight silo.*

Source: [GRDC]

MORE INFORMATION

[Fumigating with phosphine, other fumigants and controlled atmospheres]

It is recommended to pressure test silos that are sealable once a year to check for damaged seals on openings. Storages must be able to be sealed properly to ensure effective fumigation.

There is no compulsory manufacturing standard for sealed silos in Australia. A voluntary industry standard was adopted in 2010. Watch this GRDC Ground Cover TV clip to find out more.

13.1.2 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 wheat and are filled and emptied using specialised machinery (Photo 2). The bags are sealed after filling producing a relatively airtight environment which, under favourable storage conditions, protects grain from insect damage without the use of insecticides.

Potential advantages of using grain storage bags as a method for grain storage include the low capital set up costs, improved harvest management, less harvest stress, reduced harvest freight requirements, minimal cost in occupational health and safety (OH&S) requirements, reduced grain insecticide requirements and the opportunity to segregate and blend grain.

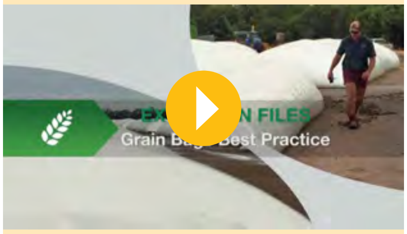
Potential disadvantages of using grain storage bags as a method for grain storage include the requirement for disposal of used bags, the period of storage before bag deterioration and the management necessary to ensure bag integrity. Another potential disadvantage of this system, when compared to permanent structures, is that once the storage period is complete there is no asset value in the storage system other than the bagging machinery. [14]

Photo 2: *A 100 m bag can be filled in 30 minutes with a constant supply of grain.*

Source: StarTribune

VIDEOS

WATCH: Grain bags best practice.



WATCH: Extension Files: Grain bags—a grower's perspective

13.1.3 Monitoring stored grain

Whatever method is used to store grain on the farm, monitoring grain temperature and moisture content should occur regularly:

- Pests and grain moulds thrive in warm, moist conditions. Monitor grain moisture content and temperature to prevent storage problems.
- Use a grain temperature probe to check storage conditions and aeration performance (Photo 3).
- When checking grain, smell air at the top of storages for signs of high grain moisture or mould problems.
- Check germination and vigour of planting seed in storage.
- Aeration fans can be used to cool and dry grain to reduce storage environment problems.

14 J Francis (2006) An analysis of grain storage bags, sealed grain silos and warehousing for storing grain, https://grdc.com.au/uploads/documents/Final%20report%20Grain%20Storage%20Bags%2021%20Jul%20061.pdf

It is vital to monitor grain moisture content to prevent pests and grain moulds from thriving. [15]

Photo 3: *Monitor moisture and temperature using a digital probe from both the top and the bottom of silos, if safe to do so.*

Source: Plant Health Australia

13.1.4 Grain storage: getting the economics right

As growers continue to expand their on-farm grain storage, the question of economic viability gains significance. There are many examples of growers investing in on-farm grain storage and paying for it in one or two years because they struck the market at the right time, but are these examples enough to justify greater expansion of on-farm grain storage?

The grain storage extension team conduct approximately 100 grower workshops every year, Australia wide, and it is evident that no two growers use on-farm storage in the exact same way. Like many economic comparisons in farming, the viability of grain storage is different for each grower. Depending on the business's operating style, the location, the resources and the most limiting factor to increase profit; grain storage may or may not be the next best investment. For this reason, everyone needs to do a simple cost benefit analysis for their own operation.

Comparing on-farm grain storage

To make a sound financial decision, we need to compare the expected returns from grain storage versus expected returns from other farm business investments—such as more land, a chaser bin, a wider boomspray, a second truck or paying off debt. The other comparison is to determine if we can store grain on-farm cheaper than paying a bulk handler to store it for us.

Calculating the costs and benefits of on-farm storage will enable a return-on investment (ROI) figure, which can be compared with other investment choices and a total cost of storage to compare to the bulk handlers.

15 Plant Health Australia (2015) Monitoring stored grain on farm, http://www.planthealthaustralia.com.au/wp-content/uploads/2015/11/Monitoring-stored-grain-on-farm.pdf

Cheapest form of storage

The key to a useful cost–benefit analysis is identifying which financial benefits to plan for and costing an appropriate storage to suit that plan. People often ask, "what's the cheapest form of storage?" The answer is the storage that suits the planned benefits. Short-term storage for harvest logistics or freight advantages can be suited to grain bags or bunkers. If flexibility is required for longer term storage, gas-tight, sealable silos with aeration cooling allow quality control and insect control.

Benefits

To compare the benefits and costs in the same form, work everything out on a basis of dollars per tonne. On the benefit side, the majority of growers will require multiple financial gains for storing grain to make money out of it. These might include harvest logistics or timeliness, market premiums, freight savings or cleaning, blending, or drying grain to add value.

Costs

The costs of grain storage can be broken down into fixed and variable. The fixed costs are those that don't change from year to year and have to be covered over the life of the storage. Examples are depreciation and the opportunity or interest cost on the capital. The variable costs are all those that vary with the amount of grain stored and the length of time it is stored for. Interestingly, the costs of good hygiene, aeration cooling and monitoring are relatively low compared to the potential impact they can have on maintaining grain quality. One of the most significant variable costs, and one that is often overlooked, is the opportunity cost of the stored grain. That is the cost of having grain in storage rather than having the money in the bank paying off an overdraft or a term loan.

The result

While it is difficult to put an exact dollar value on each of the potential benefits and costs, a calculated estimate will determine if it is worth a more thorough investigation. If we compare the investment of on-farm grain storage to other investments and the result is similar, then we can revisit the numbers and work on increasing their accuracy. If the return is not even in the ball park, we have potentially avoided a costly mistake. On the contrary, if after checking our numbers the return is favourable, we can proceed with the investment confidently.

Summary

Unlike a machinery purchase, grain storage is a long-term investment that cannot be easily changed or sold. Based on what the grain storage extension team is seeing around Australia, the growers who are taking a planned approach to on-farm grain storage and doing it well are being rewarded. Grain buyers are seeking out growers who have a well-designed storage system that can deliver insect free, quality grain without delay.

Table 2 is a tool that can be used to figure out the likely economic result of on-farm grain storage for each individual business. Each column can be used to compare various storage options including type of storage, length of time held or paying a bulk handler. [16]

MORE INFORMATION

GRDC Economics of on-farm grain storage, cost benefit analysis

Economics of on-farm grain storage: a grains industry guide

16 C Warrick (2016) GRDC Update Papers: Grain storage—get the economics right. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/09/Grain-storage-get-the-economics-right

VIDEOS

WATCH: On-farm storage in the SA Mallee with Corey Blacksell.

WATCH: On-farm storage in SA—Linden Price

WATCH: Over the Fence: On-farm storage delivers harvest flexibility and profit

WATCH: Stay safe around grain storage

Table 2: *Cost-benefit template for grain storage.*

Financial gains from storage		Example $/t
Harvest logistics/ timeliness	Grain price x reduction in value after damage % x probability of damage %	$16
Marketing	Post harvest grain price - harvest grain price	
Freight	Peak rate $/t - post harvest rate $/t	$20
Cleaning to improve grade	Clean grain price - original grain price - cleaning costs - shrinkage	
Blending to lift average grade	Blended price - ((low grade price x %mix) + (high grade price x %mix))	
Total benefits	Sum of benefits	$36.20
Capital cost	Infrastructure cost / storage capacity	$155
Fixed costs		
Annualised depreciation cost	Capital cost $/t / expected life storage e.g. 25 yrs	$6.20
Opportunity cost on capital	Capital cost $/t x opportunity or interest rate e.g. 8% / 2	$6.20
Total fixed costs	Sum of fixed costs	$12.40
Variable costs		
Storage hygiene	(Labour rate $/hr x time to clean hrs / storage capacity) + structural treatment	$0.23
Aeration cooling	Indicatively 23c for the first 8 days then 18c per month / t	$0.91
Repairs and maintenance	Estimate, e.g. capital cost $/t x 1%	$1.51
Inload/outload time and fuel	Labour rate $/hr / 60 minutes / auger rate t/m x 3v	$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

MORE INFORMATION

[Grain storage pest control options and storage systems.](#)

13.2 Stored grain pests

Key points

- Effective grain hygiene and aeration cooling can overcome 85% of pest problems.
- When fumigation is needed it must be carried out in pressure-tested, sealed silos.
- Monitor stored grain monthly for moisture, temperature and pests.
- Combining good hygiene, well-managed aeration cooling and regular grain inspections provides the best foundation for successful grain storage.

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. [17]

13.2.1 Common species

The most common insect pests of stored cereal grains in Australia are (Figure 4):

- Weevils *(Sitophilus spp.)*. Rice weevil is the most common weevil in cereals in Australia.
- Lesser Grain Borer *(Rhyzopertha dominica)*.
- Rust Red Flour Beetle *(Tribolium spp.)*.
- Sawtooth Grain Beetle *(Oryzaephilus spp.)*.
- Flat Grain Beetle *(Cryptolestes spp.)*.
- Indian Meal Moth *(Plodia interpunctella)*.
- Angoumois Grain Moth *(Sitotroga cerealella)*.

Another dozen or so beetles, psocids (booklice) and mites are sometimes present as pests in stored cereal grain.

17 GRDC Stored Grain Information Hub. Northern and Southern Regions Grain Storage Pest control guide, http://storedgrain.com.au/pest-control-guide-ns/

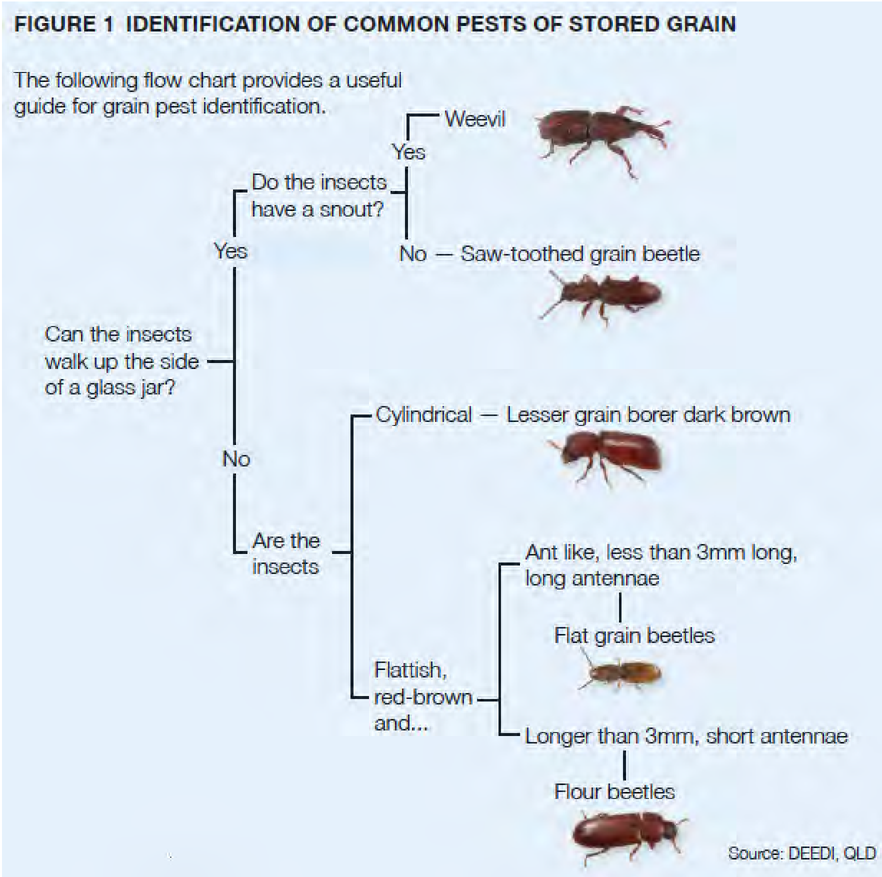


Figure 4: *Identification of common pests of stored grain.*

Source: GRDC

Why identify stored insect grain pests?

Most insect control methods for stored grain work against all species. So you don't need to identify the storage pests to make decisions about most control methods. But if you intend spraying grain with insecticides you may need to know which species are present if:

- A previous application has failed and you want to know whether resistance was the reason—if more than one species survived, resistance is unlikely to be the cause.
- You intend to use a residual protectant to treat infested grain—pyrimiphos-methyl, fenitrothion and chlorpyrifos-methyl are ineffective against lesser grain borer, and pyrimiphos-methyl and fenitrothion are generally ineffective against sawtoothed grain beetle.
- You intend to use dichlorvos to treat infested grain—if lesser grain borer is present you need to apply the higher dose rate. This then increases the withholding period before grain can be marketed from 7–28 days.

MORE INFORMATION

Stored grain pests identification

VIDEOS

WATCH: GCTV2: Grain storage insect ID

13.2.2 Monitoring grain for pests

Damage by grain insect pests often goes unnoticed until the grain is removed from storage. Regular monitoring will help to ensure that grain quality is maintained.

- Sample each grain storage at least monthly. During warmer periods of the year, fortnightly sampling is recommended.
- Take samples from the top and bottom of grain stores and sieve (using 2 mm mesh) onto a white tray to separate any insects (Photo 4).
- Hold tray in the sunlight for 10–20 seconds to trigger movement of any insects, making them easier to see. Use a magnifying glass to identify pests.
- Grain probes or pitfall traps should also be used to check for insects. These traps are left in the grain during storage and are often able to detect the start of an infestation.
- Push probe/trap into the grain surface and pull up for inspection fortnightly/ monthly. Place 1–2 traps in the top of a silo or several traps in a grain shed.
- Be sure to check grain 3 weeks prior to sale to allow time for treatment if required. [18]

Photo 4: *A 2 mm mesh sieve will separate insects from grain.*

Source: Plant Health Australia

MORE INFORMATION

GRDC Stored grain pests: the back pocket guide

Monitoring stored grain on-farm.

13.2.3 Hygiene

Key points

- Effective grain hygiene requires complete removal of all waste grain from storages and equipment.
- Be meticulous with grain hygiene—pests only need a small amount of grain for survival.

A bag of infested grain can produce more than one million insects during a year, which can walk and fly to other grain storages where they will start new infestations. Meticulous grain hygiene involves removing any grain that can harbour pests and allow them to breed. It also includes regular inspection of seed and stockfeed grain so that any pest infestations can be controlled before pests spread.

Where to clean

Removing an environment for pests to live and breed in is the basis of grain hygiene, which includes all grain handling equipment and storages. Grain pests live in dark, sheltered areas and breed best in warm conditions.

18 Plant Health Australia (2015) Monitoring stored grain on-farm, http://www.planthealthaustralia.com.au/wp-content/uploads/2015/11/Monitoring-stored-grain-on-farm.pdf

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.

Successful grain hygiene involves cleaning all areas where grain gets trapped in storages and equipment (Photo 5). Grain pests can survive in a tiny amount of grain, so any parcel of fresh grain through the machine or storage becomes infested.

Photo 5: *Grain left in trucks is an ideal place for grain pests to breed. Keep trucks, field bins and chaser bins clean.*

Source: GRDC

When to clean

Straight after harvest is the best time to clean grain handling equipment and storages, before they become infested with pests. One trial revealed more than 1,000 lesser grain borers in the first 40 litres of grain through a harvester at the start of harvest, which was considered reasonably clean at the end of the previous season. Discarding the first few bags of grain at the start of the next harvest is also a good idea. Further studies revealed insects are least mobile during the colder months of the year. Cleaning around silos in July–August can reduce insect numbers before they become mobile.

How to clean

The better the cleaning job, the less chance of pests harbouring. The best ways to get rid of all grain residues use a combination of:

- Sweeping
- Vacuuming
- Compressed air
- Blow/vacuum guns
- Pressure washers
- Fire-fighting hoses

Using a broom or compressed air gets rid of most grain residues, and a follow-up wash-down removes grain and dust left in crevices and hard-to-reach spots (Photo

6). Choose a warm, dry day to wash storages and equipment so that it dries out quickly, to prevent rusting. When inspecting empty storages, look for ways to make the structures easier to keep clean. Seal or fill any cracks and crevices to prevent grain lodging and insects harbouring. Bags of leftover grain lying around storages and in sheds create a perfect harbour and breeding ground for storage pests. After collecting spilt grain and residues, dispose of them well away from any grain storage areas.

Photo 6: *Clean silos, including the silo wall, with air or water to provide a residue-free surface to apply structural treatments.*

Source: GRDC

The process of cleaning on-farm storages and handling equipment should start with the physical removal, blowing and/or hosing out of all residues. Once the structure is clean and dry, consider the application of DE as a structural treatment. See Section 1.2.4 Structural treatments for more information.

A concrete slab underneath silos makes cleaning much easier (Photo 7).

Agronomist's view

Photo 7: *A concrete slab underneath silos makes cleaning up spilled grain much easier.*

Source: GRDC

13.2.4 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 (Table 3).

At temperatures below 15°C the common rice weevil stops developing.

At low temperatures insect pest life cycles (egg, larvae, pupae and adult) are lengthened from the typical four weeks at warm temperatures (30–35°C) to 12–17 weeks at cooler temperatures (20–23°C).

Table 3: *The effect of grain temperature on insects and mould.*

Grain temp (°C)	Insect and mould development	Grain moisture content (%)
40–55	Seed damage occurs, reducing viability	
30–40	Mould and insects are prolific	>18
25–30	Mould and insects are active	13–18
20–25	Mould development is limited	10–13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group in GRDC

For more information, see Section 13.3.2 Aeration cooling below

13.2.5 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.

VIDEOS

WATCH: Grain Silo Hygiene.

MORE INFORMATION

GRDC fact sheet, Aeration cooling for pest control

Chemicals used for structural treatments do not list the specific use before storing grains on their labels and MRLs. 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. This will ensure the DE doesn't discolour the grain surface. Diatomaceous earth is an amorphous silica commercially known as Dryacide® that acts by absorbing the insect's cuticle or protective waxy exterior, causing death by desiccation. If applied correctly with complete coverage in a dry environment, DE can provide up to 12 months of protection for storages and equipment.

If unsure, check with the grain buyer before using any product that will come in contact with the stored grain. [19]

MORE INFORMATION

Hygiene and structural treatments for grain storages.

Application

Inert dust requires a moving air stream to direct it onto the surface being treated; alternatively, it can be mixed into a slurry with water and sprayed onto the surface. See label directions. Throwing dust into silos by hand will not achieve an even coverage, so will not be effective. For very small grain silos and bins, a hand operated duster, such as a bellows duster, is suitable. Larger silos and storages require a powered duster operated by compressed air or a fan. If compressed air is available, it is the most economical and suitable option for on-farm use, connected to a venturi duster such as the Blovac BV-22 gun (Photo 8).

Photo 8: *A blow/vac or air venture gun is the best applicator for inert dusts. Aim for an event coat of diatomaceous earth across the roof, walls and base.*

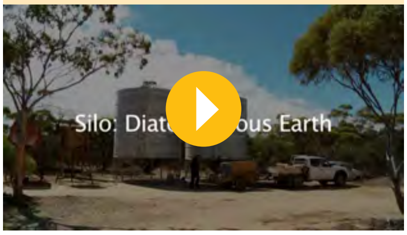
Photo: C Warrick, Proadvice

The application rate is calculated at 2 g/m^2 surface area treated. Although inert, breathing in excessive amounts of dust is not ideal, so use a disposable dust mask and goggles during application (Table 4).

19 GRDC Stored Grain information hub. Storing Pulses, http://storedgrain.com.au/storing-pulses/

VIDEOS

WATCH: Applying diatomaceous earth dust.



Silo application

Apply inert dust in silos, starting at the top (if safe) by coating the inside of the roof, then working your way down the silo walls, finishing by pointing the stream at the bottom of the silo (Table 4). If silos are fitted with aeration systems, distribute the inert dust into the ducting without getting it into the motor, where it could cause damage. [20]

Table 4: *Inert dust (diatomaceous earth) application guide.*

Storage capacity (t)	Dust quantity (kg)
20	0.12
56	0.25
112	0.42
224	0.60
450	1.00
900	1.70
1,800	2.60

Source: GRDC.

13.2.6 Fumigation

There are a number of chemical control options for the control of grain pests in stored cereals (Table 5).

Table 5: *Resistance and efficacy guide for stored grain insects. Before applying, check with your grain buyers/bulk handlers and read labels carefully.*

Treatment and example product	WHP	Lesser grain borer	Rust-red flour beetle	Rice weevil	Saw-toothed grain beetle	Flat grain beetle	Psocids (booklice)	Structural treatments
Grain disinfestants—used on infested grain to control full life cycle (adults, eggs, larvae, pupae)								
Phosphine (Fumitoxin®)[1,3] when used in gas-tight, sealable stores	2							
Sulfuryl fluoride (ProFume®)[10]	1							
Grain protectants—applied postharvest. Poor adult control if applied to infested grain								
Pirimiphos-methyl (Actellic 900®)	nil[2]							
Fenitrothion (Fenitrothion 1000®)[4, 7]	1–90							
Chlorpyrifos-methyl (Reldan Grain Protector®)[5]	Nil[2]							
'Combined products' (Reldan Plus IGR Grain Protector)	Nil[2]							
Deltamethrin (K-Obiol®)[10]	Nil[2]							
Spinosad and Chlorpyrifos-methyl (eg Conserve On-Form™)[9]								
Diatomaceous earth, amorphous silica—effective internal structural treatment for storages and equipment. Specific-use grain treatments								
Diatomaceous earth, amorphous silica (Dryacide®)[8]	Nil[2]							

Not registered for this pest
High-level resistance in flat grain beetle has been identified, send insects for testing if fumigation failures occur
Resistant species likely to survive this structural treatment for storage and equipment
Resistance widespread (unlikely to be effective)
Effective control

1 Unlikely to be effective in unsealed sites, causing resistance, see label for definitions
2 When used as directed on label
3 Total of (exposure + ventilation + withholding) = 10 to 27 days

20 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

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 9).

Taking fumigation shortcuts may kill enough adult insects in grain so it passes delivery standards, but the repercussions of such practices are detrimental to the grains industry.

Poor fumigation techniques fail to kill pests at all life cycle stages, so while some adults may die, grain will soon be reinfested again as soon as larvae and eggs develop.

What's worse, every time a poor fumigation is carried out, insects with some resistance survive, making the chemical less effective in the future.

Photo 9: *Phosphine is widely accepted as having no residue issues.*

Photo: QDAFF

While phosphine has some resistance issues, it is widely accepted as having no residue issues for grain. The grain industry has adopted a voluntary strategy to manage the build-up of phosphine resistance in pests. Its core recommendations are to limit the number of conventional phosphine fumigations on undisturbed grain to three per year, and to employ a break strategy. [21]

Maximum residue limits

By observing several precautions, growers can ensure that grain coming off their farm is compliant with the maximum pesticide residue limits that apply to Australian exports. Violations of maximum residue limits (MRLs) affect the marketability of Australian grain exports, and consequences may include costs being imposed on exporters and/or growers.

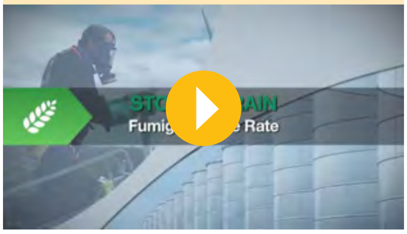
21 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry, Cooperative Research Centre for National Plant Biosecurity, http://www.graintrade.org.au/sites/default/files/file/NWPGP/Phosphine%20Resistance%20Strategy.pdf

VIDEOS

WATCH: GCTV Stored Grain. Fumigation recirculation.

VIDEOS

WATCH: GCTV Stored Grain: Phosphine Dose Rates.



Measures growers need to take to avoid MRL violations are detailed in a new *Grain Marketing and Pesticide Residues* Fact Sheet, produced by the Grains Research and Development Corporation (GRDC). The Fact Sheet states it is essential that both pre-harvest and post-harvest chemical applications adhere to the Australian Grain Industry Code of Practice, only registered products are used and all label recommendations, including rates and withholding periods, must be observed. Other key points include:

- Trucks or augers that have been used to transport treated seed or fertiliser can be a source of contamination – pay particular attention to storage and transport hygiene;
- Silos that have held treated fertiliser or pickled grain will have dust remnants – these silos either need to be cleaned or designated as non-food grade storage;
- Know the destination of your grain. When signing contracts, check the importing countries' MRLs to determine what pesticides are permitted on a particular crop. [22]

Phosphine application

For effective phosphine fumigation, a minimum of 300 parts per million (ppm) gas concentration for seven days or 200 ppm for 10 days is required. Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks. The rest of the silo also suffers from reduced gas levels.

Achieve effective fumigation by placing the correct phosphine rates (as directed on the label) onto a tray and hanging it in the top of a pressure-tested, sealed silo or into a ground level application system if the silo is fitted with recirculation.

After fumigation, ventilate grain for a minimum of one day with aeration fans running, or five days if no fans are fitted.

A minimum withholding period of two days is required after ventilation before grain can be used for human consumption or stock feed.

The total time needed for fumigating is 10–17 days.

As a general rule, only keep a silo sealed while carrying out the fumigation (for example, one to two weeks).

After fumigation has been completed, return to aeration cooling to hold the stored grain at a suitable temperature level.

Handle with care

Phosphine is a highly toxic gas with potentially fatal consequences if handled incorrectly. As a minimum requirement, the label directs the use of cotton overalls buttoned at the neck and wrist, eye protection, elbow-length PVC gloves and a breathing respirator with combined dust and gas cartridge.

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.

22 S Watt. (2014). Know your maximum residue limits. https://grdc.com.au/Media-Centre/Media-News/South/2014/07/Know-your-maximum-residue-limits

MORE INFORMATION

Grain fumigation—a guide

Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once. A Grains Industry Guide

Fumigation to control insects in stored grain

Time to kill

To control pests at all life stages and prevent insect resistance, phosphine gas concentration needs to reach 300 ppm for seven days (when grain is above 25°C) or 200 ppm for 10 days (between 15–25°C). Insect activity is slower in cooler grain temperatures so require longer exposer to the gas to receive a lethal dose. [23]

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. [24]

13.3 Aeration during storage

13.3.1 Dealing with high moisture grain

Key points

- Deal with high-moisture grain promptly.
- Monitoring grain moisture and temperature regularly (daily) will enable early detection of mould and insect development.
- Aeration drying requires airflow rates in excess of 15 L/s/t.
- Dedicated batch or continuous flow dryers are a more reliable way to dry grain than aeration drying in less-than-ideal ambient conditions.

A Department of Employment, Economic Development and Innovation (DEEDI) trial revealed that high-moisture grain generates heat when put into a confined storage, such as a silo.

Wheat at 16.5% moisture content at a temperature of 28°C was put into a silo with no aeration. Within hours, the grain temperature reached 39°C and within two days reached 46°C, providing ideal conditions for mould growth and grain damage (Figure 5). 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.

23 GRDC Stored Grain Information Hub. Grain Fumigation—A guide, http://storedgrain.com.au/fumigation-guide/

24 C Warrick (2012) Fumigating with phosphine, other fumigants and controlled atmospheres: Do It right—(2012) Fumigating with phosphine, other fumigants and controlled atmosphhttp://www.grdc.com.au/~/media/5EC5D830E7BF4976AD591D2C03797906.pdf

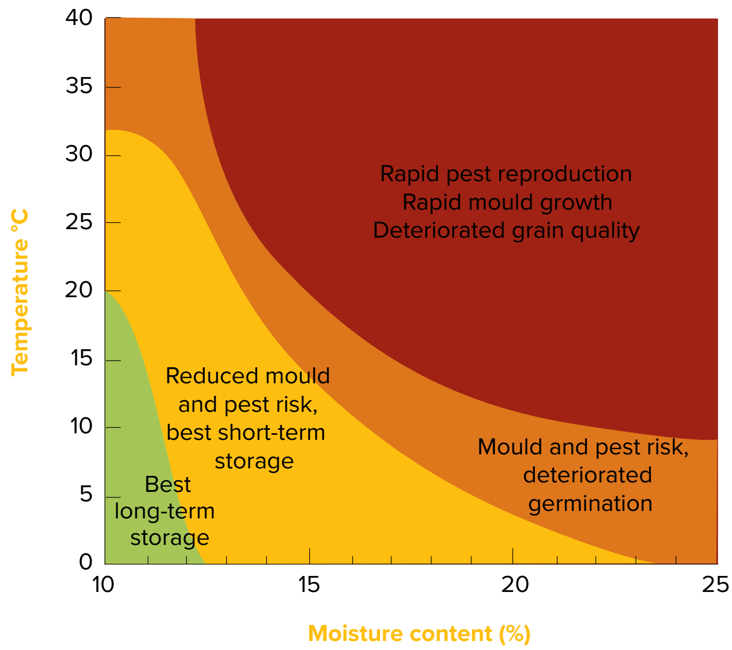


Figure 5: *Effects of Temperature and moisture on stored grain.*

Source: CSIRO Ecosystems Sciences in GRDC

13.3.2 Aeration cooling

Key points

- Grain temperatures below 20°C significantly reduce mould and insect development.
- Reducing grain temperature with aeration cooling protects seed viability.
- Controlling aeration cooling is a three-stage process—continual, rapid and then maintenance.
- Stop aeration if ambient, relative humidity exceeds 85%.
- Automatic grain aeration controllers that select optimum fan run times provide the most reliable results.

Aeration cooling can be used to reduce the risk of mould and insect development for a month or two until drying equipment is available to dry grain down to a safe level for long-term storage or deliver. In most circumstances, grain can be stored at up to 14–15% moisture content safely with aeration cooling fans running continuously, delivering at least 2–3 L/s/t. It is important to keep fans running continuously for the entire period, only stopping them if the ambient relative humidity is above 85% for more than about 12 hours, to avoid wetting the grain further.

Blending

Blending is the principle of mixing slightly over-moist grain with lower-moisture grain to achieve an average moisture content below the ideal 12.5% moisture content. Successful for grain moisture content levels up to 13.5%, blending can be an inexpensive way of dealing with wet grain, providing the infrastructure is available. Aeration cooling does allow blending in layers but if aeration cooling is not available blending must be evenly distributed (see Figure 6). [25]

25 GRDC Stored Grain Information Hub: Dealing with high moisture grain, http://storedgrain.com.au/dealing-with-high-moisture-grain/

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GRDC Aerating Stored Grain—Industry Guide

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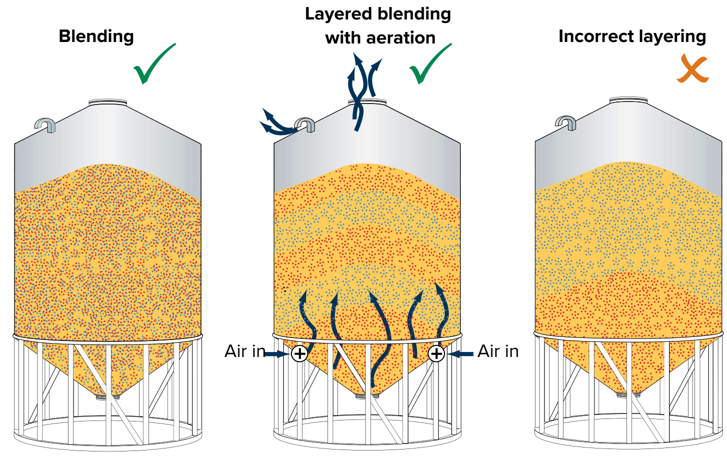

Figure 6: *Diagram demonstrating the correct practices for blending.*

Source: Kondinin Group, in GRDC

Seed viability

Research trials reveal that wheat at 12% moisture content stored for six months at 30–35°C (unaerated grain temperature) will have reduced germination percentage and seedling vigour.

13.3.3 Aeration drying

Aeration drying relies on a high air volume and is usually done in a purpose-built drying silo or a partly filled silo with high-capacity aeration fans. Aeration drying is a slow process and relies on four keys:

- High airflow rates.
- Well-designed ducting for even airflow through the grain.
- Exhaust vents in the silo roof.
- Warm, dry weather conditions.

It is important to seek reliable advice on equipment requirements and correct management of fan run times, otherwise there is a high risk of damaging grain quality.

High airflow for drying

Unlike aeration cooling, aeration drying requires high airflow, in excess of 15 l/s/t, to move drying fronts quickly through the whole grain profile and depth and carry moisture out of the grain bulk. As air passes through the grain, it collects moisture and forms a drying front. If airflow is too low, the drying front will take too long to reach the top of the grain stack—often referred to as a "stalled drying front". Providing the storage has sufficient aeration ducting, a drying front can pass through a shallow stack of grain much faster than a deep stack of grain. As air will take the path of least resistance, make sure the grain is spread out to an even depth.

Ducting for drying

The way to avoid hot spots is with adequate ducting to deliver an evenly distributed flow of air through the entire grain stack (Photo 10). A flat-bottom silo with a full floor aeration plenum is ideal providing it can deliver at least 15 l/s/t of airflow. The silo may only be able to be part filled, which in many cases is better than trying to dry grain in a cone-bottom silo with insufficient ducting.

Photo 10: *Aeration drying requires careful management, high airflow rates, well designed ducting, exhaust vents and warm, dry weather conditions.*

Source: GRDC

Venting for drying

Adequate ventilation maximises airflow and allows moisture to escape rather than forming condensation on the underside of the roof and wetting the grain on the top of the stack. The amount of moisture that has to escape with the exhaust air is 10 L for every one per cent moisture content removed per tonne of grain.

Weather conditions for drying

For moisture transfer to occur and drying to happen, air with a lower relative humidity than the grain's equilibrium moisture content must be used. For example, Table 6 shows that wheat 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 wheat from its current state, the aeration drying fans would need to be turned on when the ambient air was below 70% relative humidity.

Table 6: *Equilibrium moisture content for wheat.*

Relative humidity (%)	Temperature 15	25	35
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

Grain moisture content %)

Note: values may be different for rye grain.

Source: GRDC

MORE INFORMATION

Dealing with high moisture grain

VIDEOS

WATCH: Aeration drying—getting it right

Phase one of drying

Aeration drying fans can be turned on as soon as the aeration ducting is covered with grain and left running continuously until the air coming out of the top of the storage has a clean fresh smell. The only time drying fans are to be turned off during this initial, continuous phase is if ambient air exceeds 85% relative humidity for more than a few hours.

Phase two of drying

By monitoring the temperature and moisture content of the grain in storage and referring to an equilibrium moisture table, such as Table 6, a suitable relative humidity trigger point can be set. As the grain is dried down the equilibrium point will also fall, so the relative humidity trigger point will need to be reduced to dry down the grain further. Reducing the relative humidity trigger point slowly during phase two of the drying process will help keep the difference in grain moisture from the bottom to the top of the stack to a minimum, by ensuring the fans get adequate run time to push each drying front right through the grain stack.

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. [26]

13.3.4 Aeration controllers

Aeration controllers manage both aeration drying, cooling and maintenance functions in up to ten separate storages (Photo 11). The unit takes into account the moisture content and temperature of grain at loading and the desired grain condition after time in storage, and selects air accordingly to achieve safe storage levels.

A single controller has had the ability to control the diverse functions of aeration: cooling, drying and maintenance. The controller can not only control all three functions, but also automatically selects the correct type of aeration strategy to obtain the desired grain moisture and temperature. [27]

Research has shown that with the support of an aeration controller, aeration can rapidly reduce stored grain temperatures to a level that helps maintain grain quality and inhibits insect development.

During trials where grain was harvested at 30°C and 15.5% moisture, grain temperatures rose to 40°C within hours of being put into storage.

An aeration controller was used to rapidly cool grain to 20°C and then hold the grain between 17–24°C from November through to March.

Before replicating similar results on-farm, growers need to:

- Know the capacity of their existing aeration system.
- Determine whether grain requires drying before cooling can be carried out.
- Understand the effects of relative humidity and temperature when aerating stored grain.
- Determine the target conditions for the stored grain.

26 GRDC Stored Grain Information Hub: Dealing with high moisture grain, http://storedgrain.com.au/dealing-with-high-moisture-grain/

27 GRDC (2007) Ground Cover Issue 57—New Generation in aeration controller, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-57-Grain-Storage-Supplement/New-generation-aeration-controller

VIDEOS

WATCH: Aeration controllers with Philip Burrill

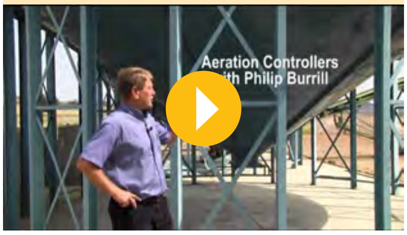

Photo 11: *Automatic aeration controllers are the most effective way to cool grain and are designed to manage many storages, from one central control unit.*

Source: GRDC

13.4 Grain protectants for storage

Lesser grain borer's (*Rhyzopertha dominica)* widespread resistance to grain protectants is coming to an end with the availability of deltamethrin (e.g. K-Obiol) and spinosad (e.g. Conserve On-Farm) products.

13.4.1 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 for use on un-infested grain and is not recommended for eradicating insect pests when they have infested grain.

The active constituent is deltamethrin. Piperonyl butoxide is added as a synergist; meaning it increases the effectiveness of the deltamethrin. As K-Obiol is based on deltamethrin there are none of the insect resistance problems being experienced with other protectants.

Because protectants are residual, there can be concern by grain users that the grain does not contain excessive levels. This may come about from incorrect treatment or double treatment as the grain moves along the supply chain. To protect the end user of the grain, and ultimately the Australian grain growers, a Product Stewardship program has been developed to ensure correct use of the product. The program will also ensure the product is used in a way that minimises the development of insect resistance and increases its usable life. [28]

13.4.2 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.

28 GRDC Stored Grain information hub. K-Obiol Combi, http://storedgrain.com.au/k-obiol-combi/

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. [29]

29 GRDC Stored Grain information hub. Conserve On-farm, http://storedgrain.com.au/conserve-farm/

Environmental issues

Key messages

- Rye can withstand sandblasting and is more tolerant of drought and frost than other cereals. [1]
- Rye is more sensitive to hot weather than oats and barley. [2]
- Rye is the most productive of the cereal grain crops under conditions of low temperature, low fertility and drought.
- Rye can tolerate acid soils better than wheat, barley or canola. [3] Cereal Rye is thought to be relatively tolerant on saline soils, similar to barley, but will be affected in highly saline soils (8–16 ECe (dS/m)). [4]

14.1 Frost issues for Cereal Rye

Key points

- Rye will make even better growth than oats under cold conditions. [5]
- Frost is estimated to cost south-east Australia at least $100 million a year in unfulfilled or lost yield potential. [6]
- Frost events can have major and sudden impacts on cereal yields (Photo 1).
- Frost is a relatively rare occurrence but some areas are more prone to it.
- There has been an increase in frost frequency in many areas in the last 20 years.
- Minor agronomic tweaks might be necessary in some frost prone areas
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect all the damage. [7]
- Cereal rye is one of the least susceptible cereals to frost and is renowned for its cold tolerance. Crop susceptibility to frost from most to least susceptible is triticale > wheat > barley > cereal rye > oats. [8]
- Flowering about two weeks later than SA Commercial, Bevy is less prone to frost, which often affects yields of the SA Commercial variety. [9]

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1 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

2 A Clark (Ed.) (2007) Managing Cover Crops Profitably, 3rd ed. Sustainable Agriculture Network, Beltsville, MD, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

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

4 PIR.SA. Testing for soil and water salinity. Factsheet No:66/00.

5 RL Reid (Ed.) (2013) The manual of Australian agriculture. Elsevier.

6 R Barr (2016) Diversity the key to balancing frost-heat risks, https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks

7 D Grey (2014) GRDC Update Papers: Frost damage in crops—where to from here? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

8 GRDC (2009) Frost risk Factsheet, https://grdc.com.au/uploads/documents/GRDC_FS_Frost.pdf

9 Agriculture Victoria (2013) Growing cereal rye, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Photo 1: *Cereal heads showing frost damage.*

Source: DAFWA

Rye is the most frost tolerant cereal species. During winters it can survive intense frost temperatures. Winter hardiness is a complex feature, which includes cold resistance and resistance to damping. Frost tolerance may be increased by land treatment, e.g. melioration, high quality of tillage and timely sowing. Cold resistant rye plants have some typical morphological and biological features. They have narrow and short rosette leaves with a microcellular structure, spreading bushes, a thicker outer epidermis wall, a short mesocytyl and therefore a deeper tillering node. Frost-resistant plants grow more slowly in autumn and have a relatively higher concentration of dry matter in their cell sap. They expend this dry matter in their growth processes and respiration in a more economical way.

Cold tolerance and antifreeze activity are induced by cold temperatures in rye. Antifreeze proteins are found in a wide range of overwintering plants where they inhibit the growth and recrystillisation of ice that forms in intercellular spaces. In rye, antifreeze proteins accumulate in response to cold, short day length, dehydration and ethylene. [10]

Clear, calm and dry nights following cold days are the precursor conditions for radiation frost (or hoar frost). These conditions are most often met during winter and spring where high pressures follow a cold front, bringing cold air from the Southern Ocean but settled, cloudless weather (Figure 1). 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

MORE INFORMATION

Frost and plant physiology: Q&A with Glenn Macdonald

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10 H Domanska (1960) The influence of the autumn and spring drought on the development of winter rye and barley. Rocz Nauk Rolniczych Ser A: 229–241, http://eurekamag.com/research/014/254/014254711.php

temperature takes to get to zero, the length of time its stays below zero and the how far below zero it gets.

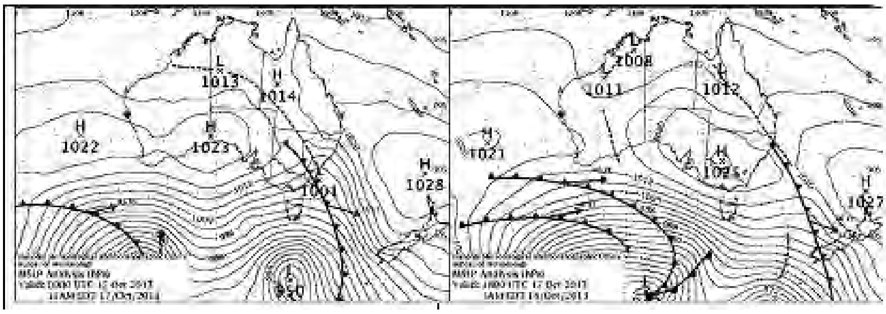

Figure 1: *A cold front passes through injecting cold air from the Southern Ocean the day before frost (left). Overnight the high pressure system stabilises over SE Australia meaning clear skies and no wind leading to a frost event (right).*

Source: GRDC

Though temperatures (particularly those in winter and spring) are getting warmer, frost is still a major issue. CSIRO researchers have found that there are areas of Australia where the number of frost events are increasing (greatest in August) with Central West New South Wales, Eyre Peninsula, Esperance and Northern Victoria (Mallee) the only major crop growing areas to be less affected by frost in the period 1961–2010 (Figure 2). This increase in frost events in much of Vic and parts of SA is thought to be caused by the latitude of the Sub Tropical Ridge of high pressure drifting south (causing more stable pressure systems) and more El Niño conditions during this period. [11]

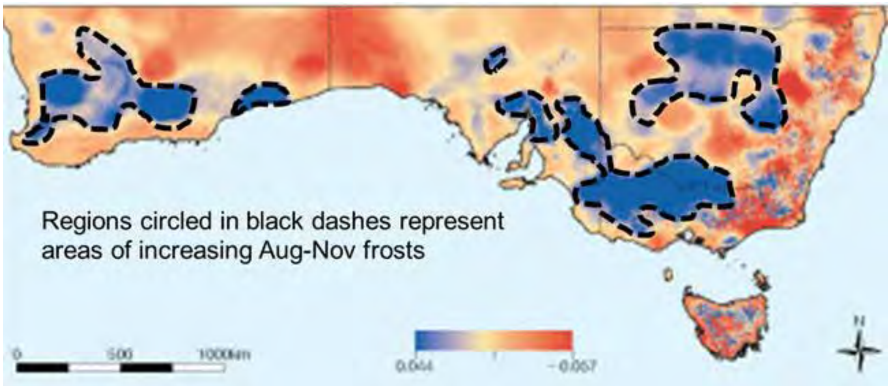

Figure 2: *Region of increasing August-November frost events.*

Source: Steven Crimp in GRDC

14.1.1 Diagnosing stem and head frost damage in cereals

Use Table 1 to help diagnose frost symptoms in your paddocks.

VIDEOS

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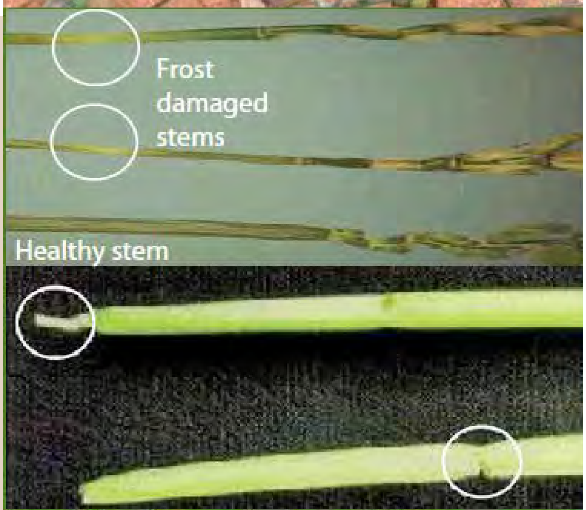
11 D Grey (2014) GRDC Update Papers: Frost damage in crops—where to from here? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

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

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 2).
- At crop maturity severely frosted areas remain green longer.
- Severely frosted crops crop have a dirty appearance at harvest due to blackened heads and stems, and discoloured leaves.

Photo 2: *Frost damage in wheat at Black Rock in the South Australian Upper North.*

Photo Jim Kuerschner. Source: GRDC

Plant

- *Before flowering:*
- Freezing of the emerging head by cold air or water is caught next to the flag leaf or travelling down the awns into the boot. Individual florets or the whole head can be bleached and shriveled, stopping grain formation. Surviving florets will form normally.
- Stem frost by a small amount of water that has settled in the boot and frozen around the peduncle. Symptoms include paleness or discolouration and roughness at the affected point on the peduncle, and blistering or cracking of nodes and leaf sheath. Stems may be distorted.
- *Flowering head:*
- The ovary in frosted flowers is "spongy" when squeezed and turns dark in colour.
- Anthers are dull coloured and are often banana shaped. In normal flowers the ovary is bright white and "crisp" when squeezed. As the grain develops it turns green in colour. Anthers are green to yellow before flowering or yellow turning white after flowering
- *Grain:*
- Frosted grain at the milk stage is white, turning brown, with a crimped appearance. It is usually spongy when squeezed and doesn't exude milk/dough. Healthy grain is light to dark green and plump, and exudes white milk/dough when squeezed (Photo 3).
- Frosted grain at the dough stage is shrivelled and creased along the long axis, rather like a pair of pliers has crimped the grain (Photo 4). [12]

Photo 3: *A normal cereal head (left) compared to frost damaged cereal showing discoloured glumes and awns.*

Source: DAFWA

12 DAFWA (2015) Diagnosing stem and head frost damage in cereals. 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.

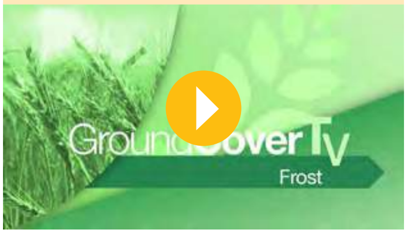


Photo 4: *Frosted hollow grain dries back to the typical shrivelled frosted grain.*

Source: GRDC

IN FOCUS

New insight in frost events and management

Take home messages:

- Growers need to consider carefully whether earlier sowing is justified in seasons where warmer temperatures are predicted.
- Warmer temperatures may reduce the frequency of frost events but also increase the rate of crop development, bringing crops to the susceptible, post-heading stages earlier.
- Situation analysis of national frost impact indicates substantial losses in all regions averaging approximately 10% using current best practice.
- There can be even greater losses in yield potential due to late sowing.
- These results indicate that continued research into reducing frost risk remains a high priority despite increasing temperatures.
- Variety guides and decision support software are useful for matching cultivars to sowing opportunities.
- Current variety ratings based on floret damage may not provide a useful guide to head and stem frost damage.
- Crops become most susceptible to frost once awns emerge.
- If crop temperature at canopy height drops below -3.5C after awn emergence, crops should be assessed for damage.
- Consider multiple sowing dates and or crops of different phenology to spread risk.

The first nationwide assessment of the comparative impact of frost in different Australian cropping regions provides important insights into how to manage frost risk in Australian cropping environments.

Climate data from 1957–2013 has been used to assess the frequency and severity of frost for each region of the Australian cropping belt. Night time minimum temperatures have been observed to increase over much of the Australian cropping region during that period. However, analysis showed that frost risk and frost impact did not reduce over the whole cropping area during that time. Warmer temperatures accelerate plant development causing crops to develop to the frost-susceptible, heading stages more rapidly. So, counter intuitively, planting earlier or even at the conventional date during warmer seasons may sometimes increase frost risk.

Historic climate data from a grid database and for 60 locations representing each of the four major cropping regions of Australia was used to determine the frequency and severity of frost (Figure 3, top). Crop simulation modelling using the Agricultural Production Systems sIMulator program (APSIM) was used to estimate crop yields. Expert knowledge combined with data from frost trials was used to estimate crop losses. Computer simulation allowed prediction of crop losses for all Australian cropping regions using damage information from a limited number of frost trial sites. It also allowed simulation of potential yields using sowing dates optimised for yield in the hypothetical absence of frost risk, something that has not been achieved experimentally.

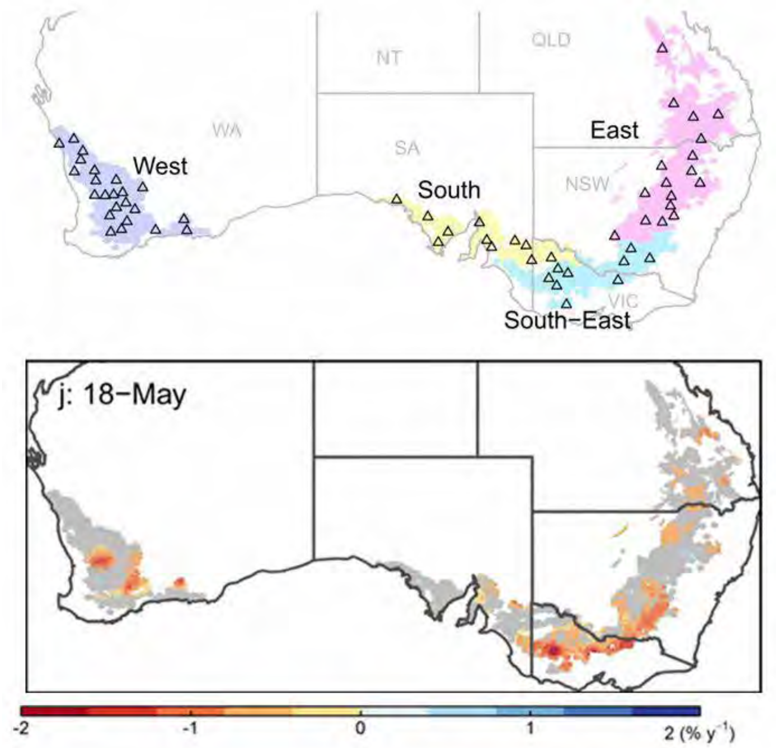


Figure 3: *Maps showing sites and regions for which climate data were analysed for the frequency and severity of frosts (top panel) and annual % change in yield loss due to frost from 1957 to 2013; negative values (yellow to red) represent areas where yield loss became worse over recent decades (bottom panel). Estimations in the lower panel were for the cultivar Janz sown 18 May and are based on a ~ 5 x 5 km grid of climatic data. (Gridded climate data may not reflect local climatic conditions of particular paddocks within each grid as frost events are highly spatially variable.)*

Source: GRDC

The researchers estimated that yield losses due to direct frost damage averaged close to 10% nationally for all crop maturity types, when current sowing guidelines were followed.

In many areas, growers must sow late to minimise frost damage. The researchers estimated the loss of yield potential for late-sown crops using a theoretical optimal sowing date (as early as 1 May). When lost yield potential from delayed sowing (indirect cost of frost) is added to direct damage (current best-sowing date), estimated yield losses doubled from

10% to 20% nationally (Figure 4, 'direct + indirect' impact). In the eastern grains region, losses were even greater, with estimated yield losses due to direct and indirect damage of 34% for early-flowering cultivars, 38% for mid-flowering and 23% for late-flowering cultivars (Figure 4).

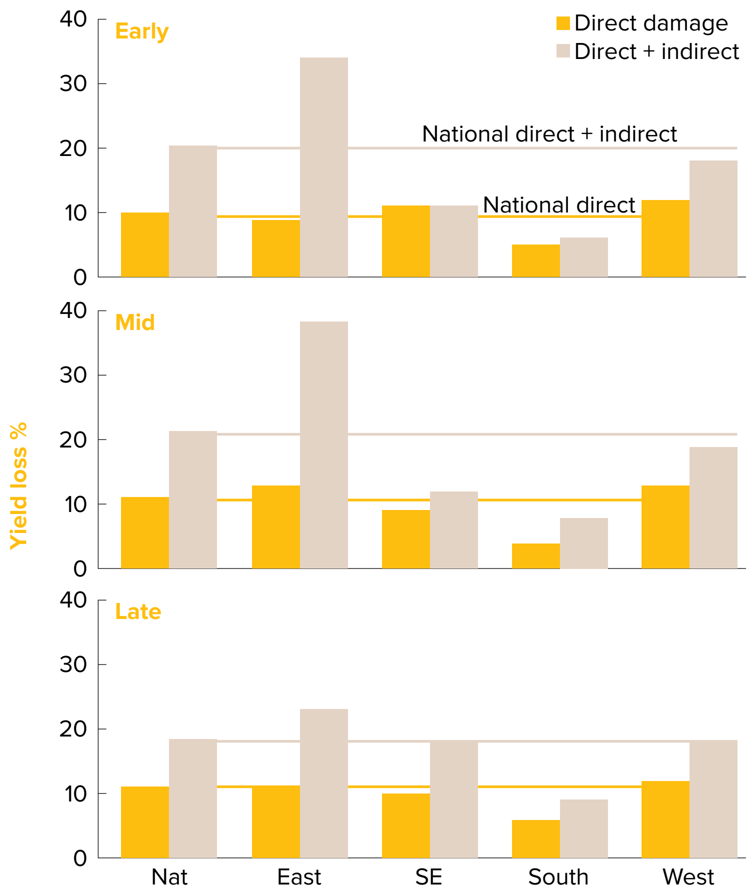


Figure 4: *Estimated wheat yield losses (%) due to frost damage for crops sown at the current best sowing date ("direct" frost damage); and crop losses due to both direct damage and delayed sowing currently necessitated to manage frost risks (direct + indirect) for early, mid and late flowering crops.*

Source: GRDC

In some areas in each region, simulated frost impact has significantly increased between 1957 and 2013 (yellow, orange and tan areas, Figure 3, bottom panel). The estimated date of last frost has changed to later in some areas and earlier in others. However, even in areas where it now comes significantly earlier, higher temperatures have also increased the rate of development to the heading stage, when the crop is more susceptible to frost. The modelling suggests that crop-heading dates have been brought forward more rapidly than the date of last frost, leading to an overall increase (in the model) in frost impact in many areas. This may actually increase the risk of frost.

Counterintuitively, yield losses were greatest in the northern grains region, with the greatest yield losses actually due to delayed sowing rather than frost per se.

These trends may force growers to change planting decisions. Sowing early to increase yield potential may now not always be the best course of action in warmer seasons, even when a lower frequency of frost events is anticipated.

These results indicate that continued research to reduce frost risk remains a high priority, despite increasing temperatures due to climate change.

Guidelines for reducing frost risk and assessing frost damage

Matching variety to planting opportunity

The current best strategy for maximising long-term crop yields is to aim for crop heading, flowering and grainfilling to be completed in the short window of opportunity between the end of the main frost risk and before day-time maximum temperatures become too high. Of course, planting in this window does not guarantee that crop loss due to frost will be averted; nor does it always prevent drastic yield reduction due to late-season heat and drought stress. However, planting a variety too early can leave growers with a very high probability of crop loss.

Seasonal temperature variations mean that the days to flowering for each variety will change from season to season. It is essential that varieties are sown within the correct window for the district as outlined in variety guides.

Current variety ratings based on floret damage may not be a useful guide, as floret-damage ratings are yet to be correlated with more significant head- and stem-damaging frosts.

Measuring crop temperature accurately

In-crop temperature measurements are useful to determine whether a crop may have been exposed to damaging temperatures. A historic comparison of on-farm and district minimum temperatures also allows growers to fine-tune management recommendations for their district to better suit their particular property, and even individual paddocks. District recommendations are based on one, or at best a few, sites, in each district and may not reflect the conditions of individual properties, so 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 by several degrees from that measured in the screen. On nights when still, cold air, clear skies, and low humidity combine, temperatures can drop rapidly, resulting in radiant frost (Figure 5). The crop temperatures recorded can vary widely due to differences in topography, micro-environment and recording method.

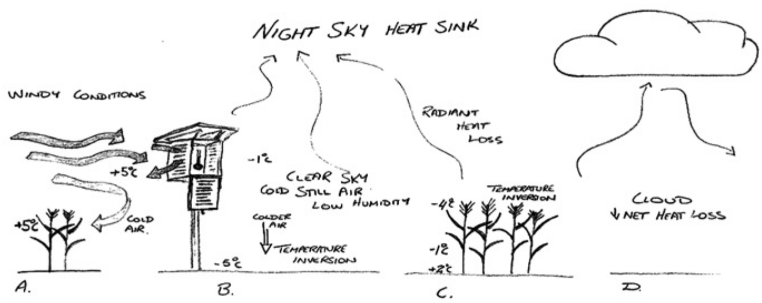


Figure 5: *If clear skies and still, cold, low humidity air coincide, heat can be lost rapidly to the night sky resulting in a radiant frost. Minimum air temperatures measured at head height can be several degrees colder than reported "screen" temperatures. Some indicative temperatures are*

illustrated for (A) windy conditions, (B) clear still conditions in an open area, (C) clear still conditions in a cropping area, and (D) cloudy conditions.

Measurements taken using exposed thermometers at canopy height (Photo 5) give a much more accurate indication of the likelihood of crop damage. [13]

Photo 5: *Canopy temperature measured using a calibrated minimum/maximum thermometer. For best results, a minimum of two or three field thermometers are require to give representative temperatures for a crop. In undulating country, more thermometers should be used to record temperatures at various heights in the landscape.*

Source: GRDC

14.1.2 Managing frost risk

Key points

- In some areas the risk of frost has increased due to widening of the frost event window and changes in grower practices.
- The risk, incidence and severity of frost varies between and within years as well as across landscapes, so growers need to assess their individual situation regularly.
- Frosts generally occur when nights are clear and calm and follow cold days. These conditions occur most often during winter and spring.
- The occurrence of frost and subsequent frost damage to grain crops is determined by a combination of factors including: temperature, humidity, wind, topography, soil type, texture and colour, crop species and variety, and how the crop is managed.
- Greatest losses in grain yield and quality are observed when frosts occur between the booting and grain ripening stages of growth.
- Frost damage is not always obvious and crops should be inspected within five to seven days after a suspected frost event.

13 J Christopher, G Zheng, S Chapman, A Borrell, T Frederiks, K Chenu (2016) GRDC Update Papers: An analysis of frost impact plus guidelines to reduce frost risk and assess frost damage, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/An-analysis-of-frost-impact-plus-guidelines-to-reduce-frost-risk-and-assess-frost-damage

- Methods to deal with the financial and personal impact of frost also need to be considered in a farm management plan.
- Careful planning, zoning and choosing the right crops are the best options to reduce frost risk. [14]

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.

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 risk attitude. The risk of frost can often drive 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 historic seasonal records and forecasts. Spatial variability (topography and soil type) across the landscape should also be considered, as cold air will flow into lower regions. Temperature monitoring equipment, such as Tiny Tags, 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 to spread financial risk in the event of frost damage. This is subject to the location of the business and skillset of the manager, but the largest financial losses with frost have occurred where growers have a limited range of enterprises or crop types. Intensive cropping systems, especially focused only on canola and spring wheat, are often more at the mercy of frost than a diversified business as both crops are highly susceptible to frost damage.

Step 4: Zone property/paddock

Paddocks or areas in paddocks that are prone to frost can be identified through past experience, the use of precision tools such as topographic, electromagnetic and yield maps, and temperature monitors to locate susceptible zones. This can help determine the appropriate management practice to use to mitigate the incidence of frost. Be aware that frost-prone paddocks can be high yielding areas on a farm when frosts do not occur.

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.

14 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

VIDEOS

WATCH: Frost Initiative: Do micronutrients reduce frost risk?

WATCH: MPCN: Copper and frost relationship investigated.

Step 2: Review nutrient management

Targeting fertiliser (nitrogen, phosphorus, potassium) on high risk paddocks and seed rates to achieve realistic yield targets should minimise financial exposure, reduce frost damage and increase whole paddock profitability over time. These nutrients could be reallocated to lower risk areas of the farm.

While high nitrogen (N) increases yield potential, it will also promote vegetative biomass production and increase 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 this may increase susceptibility to frost events. This can be assessed from initial soil tests and with plant tissue testing.

Copper deficiency can be ameliorated with a foliar spray pre-flowering and as late as the booting stage to optimise yield, even in the absence of frost.

Potassium (K) plays a role in maintaining cell water content in plants, which can potentially influence tolerance to frost. It has been shown that plants deficient in K are more susceptible to frost. Soils that are deficient in K could benefit from increasing K levels at the start of the growing season. However, it is unlikely that there will be a benefit of extra K applied to plants that are not K-deficient.

Frost tolerance cannot be bought by applying extra P or copper (Cu) to a crop that is not deficient. There is no evidence that applying other micronutrients has any impact to reduce frost damage.

Step 3: Modify soil heat bank

The soil heat bank is important for reducing the risk of frost (Figure 6). Heat is released from the soil heat-bank more slowly to warm the crop canopy at head height in early morning when frosts are more severe. It is managed by using farming practices that manipulate the storage and release of heat from the soil heat-bank into the crop canopy at night.

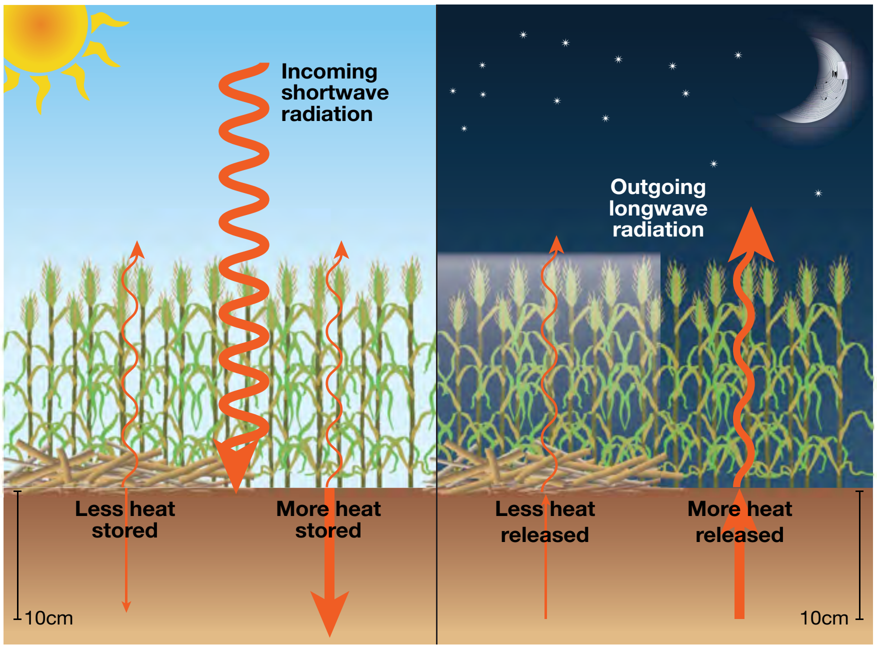


Figure 6: *The soil heat bank has an important role. It captures heat during the day and radiates heat into the crop canopy overnight to warm flowering heads and minimise frost damage. A range of farming practices can be utilised to increase the capacity of the soil heat bank.*

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. These 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 it be necessary.
- Reducing the amount of stubble: stubble loads above 1.5 t/ha in low production environments (2–3 t/ha) and 3 t/ha in high production environments (3–5 t/ha) generally increase the severity and duration of frost events and have had a detrimental effect on yield under frost.
- Halving the normal seeding rates can reduce frost severity and damage by creating a thinner canopy and more tillers resulting in a spread of flowering time. However, weed competitiveness can be an issue.
- Cross-sowing/seeding: crops sown twice with half the seed sown in each direction have a more even plant density. Heat is released from the soil heat bank more slowly to warm the crop canopy at head height in early morning when frosts are more severe. This practice, however, increases sowing costs.

Step 4: Select appropriate crops

Crop selection is an important factor to consider for frost-prone paddocks. Crops grown for hay are harvested for biomass and avoid grain loss from frost. Pasture rotations are a lower risk enterprise and oats are the most frost tolerant crop during the reproductive stage. Barley is more tolerant than wheat at flowering, but it is not known if barley and wheat have different frost tolerance during grain fill. Canola is an expensive crop to risk on frost-prone paddocks due to high input costs.

Yield Prophet and Flower Power (DAFWA) are useful tools to match the flowering time of varieties to your own farm conditions.

Step 5: Manipulate flowering times

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.

When wheat is 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 choosing sowing dates and varieties with different phenology drivers so crops flower over a wide window throughout the season. It should be noted that flowering later than the frost may result in lower yields in seasons with hot, dry finishes due 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 cereal first, then a long-season spring cereal or a day-length-sensitive cereal, and lastly an early-maturing cereal. This sets the program up for flowering to occur over a two-week period, potentially exposing the crop to more frost risk but maximising the yield potential in the absence of frost. It is possible for crops to be frosted more than once but, flowering over a wide window will probably mean that some crop will be frosted but that losses are reduced.

Sowing time remains a major driver of yield in all crops, with the primary objective being to achieve a balance between crops flowering after the risk of frost has passed and before the onset of heat stress. Farmers who sow at the start of a variety's preferred window will achieve higher yields at the same cost as sowing late. 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.

In some trials, researchers have found that blending a short-season variety with a long-season variety is an effective strategy. However, the same effect can be achieved by sowing one paddock with one variety and a second with another variety to spread risks.

Yield Prophet is a useful tool to match the flowering time of varieties to your own farm conditions.

IN FOCUS

Diversity the key to balancing frost and heat stress risks

Sowing a range of cultivars in their ideal sowing windows will give growers the best chance of balancing the increasing risks of heat and frost damage. It is more important than ever to optimise the sowing window so that, as much as possible, the entire crop flowers in its ideal window to minimise the risk of frost or heat damage.

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.

Growers who plant the majority of their cereal program using a single high-performing cultivar struggle to plant their whole program in a time close to the ideal sowing window. This can result in flowering occurring earlier or later than desired. This then leads to a higher heat stress risk if sowing is delayed or higher frost risk if planting too early.

For example, if the ideal sowing window is considered to be about five days either side of the target date, growers who sow a single cultivar over three weeks will have sown at least half of their crop (11 days out of 21) outside of this window. By comparison, if the cereal program was split up into two cultivars, almost 100% of the crop can be sown in its ideal window.

It would be impossible to choose a combination of sowing time and cultivars that would prevent exposure to heat and frost risk. However, time of sowing trials in South Australia and Victoria have shown that certain strategies will give crops the best chance. Depending on the local climate and duration of the sowing program, growers can take a few different approaches to optimise time of sowing.

In many regions of Victoria, growers can start with a winter cereal after a rain in April, then move onto slow-spring cereals and then mid-fast cultivars in May. The different maturity drivers of the cultivars mean that they still flower in the ideal window despite being sown at different times, meaning that overall yield is optimised and risk is minimised.

A time of sowing trial at Berriwillock in Victoria showed that where there is soil moisture, sowing early can provide higher yields than traditional sowing dates. In this trial, early rains were simulated with 8 mm of irrigation; most winter cereals should not be sown dry.

Currently, winter cereals do not perform particularly well in South Australia. However, three years of trials have shown that incorporating different cultivars improves overall results.

Three years of trials across multiple environments in SA have shown that yields decline at a rate of 28 kg/ha per day once sowing extends past the end of the first week in May. In order to maximize average yields, growers should therefore aim to finish seeding by mid-May.

The best strategy to manage heat and frost risk is diversity. By choosing a range of crops, cultivars with different maturity drivers and optimum sowing dates, growers will have the highest percentage of their program flowering in its ideal window.

The opportunities to take advantage of early sowing have never been better. Previous barriers have been overcome through no-till technologies, summer fallow management and cheaper chemistries to control early pests and diseases.

Researchers are working on developing new cultivars that are better suited for sowing early. But there is no reason most growers can't spread out their sowing by incorporating a few different cultivars with different maturity drivers.

While aiming for all of a farm's crop to flower at the same time runs against conventional wisdom of spreading flowering dates over a broad period to minimise exposure to single extreme frost or heat events, studies have shown the conventional logic is not the best approach.

Spreading flowering dates out so they are before or after the optimal period is a bad way of managing frost and heat risk, because the really extreme frost and heat events will affect crops at a very broad range of growth stages. Modelling shows that yields are maximised and variability minimised by getting as much crop to flower during the optimal window as possible.

Growers are better off managing risk by including a variety of crops into their program, including frost tolerant crops like rye, barley or oats, and considering further diversification such as the inclusion of hay or livestock into the business. [15]

Step 6: Fine tune cultivar selection

No wheat or barley varieties are tolerant to frost. Consider using wheat and barley varieties that have lower susceptibility to frost during flowering, to manage frost risk of the cropping program while maximising yield potential. There is no point selecting less susceptible varieties for the whole cropping program if there is an opportunity cost of lower yield without frost.

Preliminary ranking information for current wheat and barley varieties for susceptibility to reproductive frost is available from the National Variety Trial website. A new variety should be managed based on how known varieties of similar ranking are currently managed.

Post-frost event management tactics

Once a frost event (especially at or after flowering) has occurred, the first step is to inspect the affected crop and collect a (random) sample of heads to estimate the yield loss incurred.

In the event of severe frost (Photo 6) monitoring needs to occur for up to two weeks after the event to detect all the damage. After the level of frost damage is estimated, the next step is to consider options for the frost damaged crop.

15 R Barr (2016) Diversity the key to balancing frost-heat risks, https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks

Photo 6: *Severely frosted areas mature later and are often stained/discoloured.*

Source: DAFWA

Option 1: Take through to harvest

If the frost is prior to or around (growth stage) GS31 to GS32, most cereals can produce new tillers to compensate for damaged plants, provided spring rainfall is adequate. Tillers already formed but lower in the canopy may become important and new tillers can grow after frost damage, depending on the location and severity of the damage. These compensatory tillers will have delayed maturity, but where soil moisture reserves are high, or it is early in the season, they may be able to contribute to grain yield.

A later frost is more concerning, especially for crops such as wheat and barley, as there is less time for compensatory growth. The required grain yield to recover the costs of harvesting should be determined using gross margins.

Option 2: Cut and bale

This is an option when late frosts occur during flowering and through grain fill. Assess crops for hay quality within a few days of a frost event and be prepared to cut a larger area than originally intended pre-season. Producing hay can also be a good management strategy to reduce stubble, weed seed bank and disease loads for the coming season. This may allow more rotational options in the following season to recover financially from frost, for example to go back with cereal on cereal in paddocks cut early for hay. Hay can be an expensive exercise. Growers should have a clear path to market or a use for the hay on farm before committing.

Option 3: Grazing, manuring and crop topping

Grazing is an option after a late frost, when there is little or no chance of plants recovering, or when hay is not an option. Spraytopping for weed seed control may also be incorporated, especially if the paddock will be sown to crop the next year. Ploughing in the green crop is to return organic matter and nutrients to the soil, manage crop residues, weeds and improve soil fertility and structure. The economics need to be considered carefully. [16]

Table 2: *Management options for frost damaged crop, each with advantages and disadvantages.*

Options	Potential Advantages	Potential Disadvantages
Harvest	Salvage remaining grain More time for stubble to break down before sowing Machinery available	May be greater than return Need to control weeds Threshing problems Removal of organic matter
Hay / Silage	Stubble removed Additional weed control	Costs $35–$50/t to make hay Quality may be poor Nutrient removal
Chain / Rake	Retains some stubble (Reduces erosion risk) Allows better stubble handling	Costs $5/ha raking Time taken
Graze	Feed value	Inadequate stock to use feed Remaining grain may cause acidosis Stubble may be difficult to sow into
Spray	Stops weeds seeding Preserves feed quality for grazing Gives time for final decisions Retains feed Retains organic matter	Difficulty getting chemicals onto all of the weeds with a thick crop May not be as effective as burning Boom height limitation Expense $5/ha plus cost of herbicide Some grain still in crop
Plough (Cultivate)	Recycles nutrients and retains organic matter. Stop weed seed set Green manure effect	Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swath	Stops weed seed set Windrow can be baled Regrowth can be grazed Weed regrowth can be sprayed	Relocation of nutrients to windrow Low market value for straw Poor weed control under swath Expense—swathing ($20/ha) Spraying ($5/ha per herbicide)
Burn	Recycles some nutrients Controls surface weed seeds Permits re-cropping with disease control Can be done after rain	Potential soil and nutrient losses Fire hazard Organic matter loss

Source: GRDC

Useful tools

There are numerous useful tools that can help growers decisions about aspects of cropping to maximise yields in frost-prone areas. Among them are:

- Bureau of Meteorology's BOM Weather app

16 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

MORE INFORMATION

Managing frost risk—a guide for southern Australian growers.

Ranking cereals for frost susceptibility using frost values—southern region.

GRDC Managing frost risk Factsheet.

VIDEOS

WATCH: GCTV3: Frost R&D.

WATCH: GCTV16: National Frost Initiative.

- Plant development and yield apps—MyCrop and Flower Power (both from DAFWA), Yield Prophet (although it does not cover cereal rye)
- Temperature monitors such as Tinytag

National Frost Initiative

The objective of the GRDC's National Frost Initiative is to provide the Australian grains industry with targeted research, development and extension solutions to manage the impact of frost and maximise seasonal profit.

The initiative is addressing frost management through a multidisciplinary approach incorporating projects in the following programs:

1. Genetics: developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.
2. Management: developing best practise crop canopy, stubble, nutrition and agronomic management strategies to minimise the effects of frost, and searching for innovative products that may minimise the impact of frost.
3. Environment: predicting the occurrence, severity and impact of frost events on crop yields and frost events at the farm scale to enable better risk management. [17]

14.2 Waterlogging/flooding issues for cereal rye

Key points

- Waterlogging occurs when roots cannot respire due to excess water in the soil profile.
- Though cereals can be more prone to waterlogging, rye can withstand some degree of waterlogging conditions. [18]
- Water does not have to appear on the surface for waterlogging to be a potential problem.
- Improving drainage from the inundated paddock can decrease the period at which the crop roots are subjected to anaerobic conditions.
- While raised beds are the most intensive management strategy, they are also the most effective at improving drainage.
- Waterlogged soils release increased amounts of nitrous oxide (N_2O), a particularly damaging greenhouse gas.

Waterlogging occurs whenever the soil is so wet that there is insufficient oxygen in the pore space for plant roots to be able to adequately respire (Photo 7). Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and affect the plants.

Plants differ in their demand for oxygen. There is no universal level of soil oxygen that can identify waterlogged conditions for all plants. In addition, a plant's demand for oxygen in its root zone will vary with its stage of growth. [19]

17 GRDC (2016) Tips and tactics; Managing frost risk, http://www.grdc.com.au/ManagingFrostRisk

18 Agriculture Victoria (2013) Growing cereal rye, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

19 Soilquality.org. Waterlogging Factsheet, http://soilquality.org.au/factsheets/waterlogging

Photo 7: *The 2016 July wet impacted producers in Murrumburrah.*

Source: Harden Express

Cereals can be sensitive to soil waterlogging, however, many rye cultivars show good tolerance to waterlogged conditions. Rye will grow in heavy clays and poorly drained soils, and many cultivars tolerate waterlogging. [20]

IN FOCUS

Comparison of waterlogging and drought tolerances among winter cereals

Researchers wanted to quantitatively evaluate the tolerance to waterlogging and drought of the winter cereals hulled barley, naked barley, wheat, rye and oats. They grew these plants under waterlogged (W) and drought (D) conditions from seven weeks after sowing up to maturity. During this time, they measured the growth, dry-matter production and transpiration coefficients, and compared them with those of the same plants grown under moderate soil-moisture (M) conditions.

Plant growth was relatively depressed under both W and D conditions compared with that under M conditions. Naked barley, wheat, rye and oats produced more dry matter of the whole plant under D conditions than under W, while hulled barley produced more dry matter under W conditions

20 A Clark (ed.) 2007 Rye. In Managing Cover Crops Profitably. 3rd edn. Sustainable Agriculture Network, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

than under D. They considered that a crop was stable to W or D conditions when the ratio of its transpiration coefficient under W and D conditions to that under M conditions was close to or below 1.0, and was susceptible when the ratio was above 1.0. Therefore, naked barley, wheat, rye and oats were considered to have relatively large drought tolerance capacities (RLDTC), and that hulled barley had relatively large waterlogging tolerance capacities (RLWTC). Among the crops with RLDTC, rye and oats were very susceptible, and naked barley and wheat were relatively susceptible. Hulled barley, which had RLWTC, was stable to W conditions. All of the crops were stable to D conditions. [21]

Where does waterlogging occur?

Waterlogging occurs:

- Where water accumulates in poorly drained areas such as valleys, at the change of slope or below rocks.
- In duplex soils, particularly sandy duplexes with less than 30 cm sand over clay.
- In deeper-sown crops.
- in crops with low levels of nitrogen.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [22]

Waterlogging also greatly increases crop damage from salinity. Germination and early growth can be much worse on marginally saline areas after waterlogging events.

IN FOCUS

Crop production in the high rainfall zones of southern Australia—potential, constraints and opportunities

Annual cropping has been expanding in the high rainfall zone of southern Australia. The higher rainfall and longer growing season compared with the traditional wheat belt contribute to a much higher yield potential for major crops. Potential yields range from 5 to 8 t/ha for wheat and 3 to 5 t/ha for canola, although current crop yields are only about 50% of those potentials. The large yield gap between current and potential yields suggests that there is an opportunity to lift current yields. Both genetic constraints and subsoil constraints such as waterlogging, soil acidity, sodicity, and high soil strength contribute to the low yields. Waterlogging is a widespread hidden constraint to crop production in the region. Controlling waterlogging using a combination of raised beds and surface or subsurface drains is the first step to raise the productivity of the land. Increasing root growth into the subsoil remains a key to accessing more water and nutrients for high yield through early planting, deep ripping, liming and use of primer crops to ameliorate the subsoil. In order to realise the high yield potential, it is essential to achieve higher optimum dry matter at anthesis and high ear number through agronomic management, including early sowing with appropriate cultivars, a high seeding rate and application of adequate nitrogen along with other nutrients. Current cultivars of spring wheat may not fully utilise the available growing season and may have genetic limitations in sink capacity that constrain potential yield. Breeding or identification of long-season milling wheat cultivars that

21 ' ' ' , ' ' ' ' , ' ' ' , & ' ' ' ' (Yamaneuchi, Kawano Komuro, Tatsurojiro, & Inayaki Hideo.) (1988) Comparison of the capacities of waterlogging and drought tolerances among winter cereals. Japanese Journal of Crop Science. 57 (1), 163–173.

22 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

can fully utilise the longer growing season and with the ability to tolerate waterlogging and subsoil acidity, and with disease resistance, will give additional benefits. It is concluded that improving crop production in the high rainfall zone of southern Australia will require attention to overcoming soil constraints, particularly waterlogging, and the development of longer-season cultivars. [23]

Identifying problem areas

The best way to identify problem areas is to dig holes about 40 cm deep in winter and see if water flows into them (Photo 8). If it does, the soil is waterlogged. Digging holes for fence posts often reveals waterlogging. Some farmers put slotted PVC pipe into augered holes. They can then monitor the water levels in their paddocks.

Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- Presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [24]

Photo 8: *Water fills a hole dug in waterlogged soil.*

Source: Soilquality.org

14.2.1 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.

Lack of oxygen in the root zone of a plant results in anaerobic conditions that cause its root tissues to decompose. Usually this occurs from the tips of roots, and this causes 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 long enough the plant will die.

23 H Zhang, NC Turner, ML Poole, N Simpson (2006) Crop production in the high rainfall zones of southern Australia—potential, constraints and opportunities. *Animal Production Science*, *46*(8), 1035-1049.

24 Soilquality.org. Waterlogging Factsheet, http://soilquality.org.au/factsheets/waterlogging

Most often, waterlogging does not last long enough for the plant to die, and once the water drains, the plants recommence respiring. As long as the soil is moist, the older roots close to the surface allow the plant to survive. However, further waterlogging-induced root pruning or dry conditions may weaken the plant to the extent that it will do very poorly 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 water collecting areas, particularly on shallow duplex soils (Photo 9).
- Wet soil and/or water-loving weeds present.
- Early plant senescence in waterlogging prone areas.

Photo 9: *Pale plants in waterlogged areas.*

Source: DAFWA

What to look for in plants

- Plants are particularly vulnerable from seeding to tillering, with seminal roots being more affected than later forming nodal roots.
- Waterlogged seed will be swollen and may have burst.
- Seedlings may die before emergence or be pale and weak.
- Waterlogged plants appear to be nitrogen deficient with pale plants, poor tillering, and older leaf death.
- If waterlogging persists, roots (particularly root tips) cease growing, become brown and then die (Photo 10).
- Seminal roots are important for accessing deep subsoil moisture. If damaged by waterlogging the plants may be more sensitive to spring drought.

Photo 10: *Waterlogged roots (particularly seminal roots and tips) become brown and then die.*

Source: DAFWA

How can waterlogging be monitored?

- Water levels can be monitored with bores or observation pits, but water tables can vary greatly over short distances.
- Plants can be waterlogged if there is a water table within 30 cm of the surface and no indication of waterlogging at the surface. Observe plant symptoms and paddock clues and verify by digging a hole. [25]

Other impacts of waterlogging and flood events

Heat from stagnant water

Stagnant water, particularly if shallow, can heat up in hot sunny weather and kill plants in a few hours. Remove excess water as soon as possible after flooding to give plants the best chance of survival.

Chemical and biological contaminants

Floodwater may carry contaminants, particularly from off-farm run-off. You should discard all produce exposed to off-farm run-off, particularly leafy crops.

Make sure you take food safety precautions and test soils before replanting, even if crops look healthy. Contaminants will reduce over time with follow-up rainfall and sunny weather.

25 DAFWA (2015) Diagnosing waterlogging in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

VIDEOS

WATCH: GCTV3: Big Wet—Managing strategies after flooding.

WATCH: Over the Fence: Raised beds boost yields at Winchelsea.

Iron chlorosis or nitrogen deficiency

Floods and high rainfall can leach essential nutrients from the soil, which can affect plant health. Nutrients such as iron and nitrogen can be replaced through the use of fertiliser.

Soils with high clay content

High clay content means soils can become compacted and form a surface crust after heavy rainfall and flooding. Floodwater also deposits a fine clay layer or crust on top of the soil, which prevents oxygen penetration into the soil (aeration). This layer should be broken up and incorporated into the soil profile as soon as possible.

Pests and diseases

Many diseases are more active in wet, humid conditions and pests can also cause problems. Remove dying or dead plants that may become an entry point for disease organisms or insect pests. Apply suitable disease control measures as soon as possible and monitor for pests. [26]

14.2.2 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 machinery costs. [27]
  (For more information on raised beds see Cropping on raised beds in southern NSW).

Drainage is usually the best way of reducing waterlogging. Other management options to reduce the impact of waterlogging include: choice of crop, seeding, fertiliser and weed control.

Drain waterlogged soils as quickly as possible, and cultivate between rows to aerate the soil.

Good drainage is essential for maintaining crop health. Wet weather provides a good opportunity to improve the drainage of your crop land, as it allows you to identify and address any problem areas.

There are several things you can do to improve crop drainage, immediately and in the longer term.

Drainage problems after flooding

After significant rain or flooding, inspect the crops when it is safe to do so and mark areas (e.g. with coloured pegs) that are affected by poor drainage. If possible, take immediate steps to improve the drainage of these areas so that the water can get away (e.g. by digging drains).

Irrigation after waterlogging

To avoid recurrence of waterlogging, time irrigation by applying small amounts often until the crop's root system has recovered.

Ways to improve drainage

In the longer term, look for ways to improve the drainage of the affected areas. Options might include:

- re-shaping the layout of the field

26 Queensland Government (2016) Managing risks to waterlogged crops, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/managing-risks-waterlogged-crops

27 DAFWA (2015) Diagnosing waterlogging in cereals, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

- improving surface drainage
- installing subsurface drainage.

If the drainage can't be improved, consider using the area for some other purpose (e.g. for a silt trap). [28]

Choice of crop species

Some species of grains crop are more tolerant 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 paddocks that are susceptible to waterlogging first. However, if waterlogging delays emergence and reduces cereal plant density to fewer than 50 plants/m^2, re-sow the crop.

Seeding rates

Increase sowing rates in areas susceptible to waterlogging to give some insurance against uneven germination, and to reduce the dependence of cereal crops on tillering to produce grain. Waterlogging depresses tillering. High sowing rates will also increase the competitiveness of the crop against weeds, which take advantage of stressed crops.

Nitrogen fertiliser

Crops tolerate waterlogging better with a good N status before waterlogging occurs. Applying N at the end of a waterlogging period can be an advantage if N was applied at or shortly after seeding, because it avoids loss by leaching or denitrification. However, N cannot usually be applied from vehicles when soils are wet, so consider aerial applications.

If waterlogging is moderate (7–30 days waterlogging to the soil surface), then N application after waterlogging events when the crop is actively growing is recommended where basal N applications were 0–50 kg N/ha. However, if waterlogging is severe (greater than 30 days to the soil surface), then the benefits of N application after waterlogging are questionable. But this recommendation requires verification in the field at a range of basal N applications using a selection of varieties.

Weed density affect a crop's ability to recover from waterlogging. Weeds compete for water and the small amount of remaining N, hence the waterlogged parts of a paddock are often weedy and require special attention if the yield potential is to be reached. [29]

14.3 Other environmental issues for cereal rye

14.3.1 Drought

Drought is one of the major environmental factors reducing grain production in rainfed and semiarid regions. Rye is quite drought resistant. Plants cope with drought stress by manipulating key physiological processes such as photosynthesis, respiration, water relations, antioxidant and hormonal metabolism.

As the most drought resistant of cereals, rye has an extensive root system and adjusts maturity to moisture (Photo 11). It uses 20–30% less water per unit of dry matter formed than wheat. Tetraploid varieties are more sensitive to drought than diploids. In Australia's extensive arid regions, rye withstands adverse conditions better than other cereals. Its drought resistance and ability to withstand sand blasts enable it to produce soil-binding cover on land where other cereals will not grow.

MORE INFORMATION

Should waterlogged crop be top-dressed with N fertiliser?

VIDEOS

WATCH: The 2012 N story and planning for 2013.

28 Queensland Government (2016) Improving drainage of crop land, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/improving-drainage-crop-land

29 DAFWA (2015) Management to reduce the impact of waterlogging in crops, https://www.agric.wa.gov.au/waterlogging/management-reduce-impact-waterlogging-crops

VIDEOS

WATCH: MEF research breaking ground in drought tolerance.

Under conditions where wheat, oat, or barley will grow only a few centimetres high, or may even be completely blown away, rye often grows vigorously and reaches a height of a metre or more. [30]

Photo 11: *Cereal Rye showing large root system during a drought year with less above ground plant growth.*

Source: Kauffman Seed

IN FOCUS

The influence of the autumn and spring drought on the development of winter rye and barley.

Researchers reported on their experiments on how autumn soil dryness influenced the development of winter rye and barley. The experiments were carried out in different years. Some plants were grown in the autumn in dry soil (about 25% of water capacity), and were compared with others grown in wetter soil (60% or 70% of the soil water capacity). The first group showed greater resistance against the winter period. The plants dried up in the autumn, but in the spring they grew rapidly and produced higher stems and bigger yields of straw and grain than the plants that had been grown in wetter soil.

They concluded that when drought occurs during gametogenesis (the formation of gametes in the anther and ovule), the sensitivity of plants is not affected by autumn drought. In fact, autumn dryness allows the plants to recover quickly once spring arrives and growth accelerates. In natural conditions, soil dryness is linked with atmospheric dryness, which may cause damage if it is prolonged. However, under normal conditions dry soil stimulates rye and barley to a quicker growth in the depth of the root system, which may make the plants less sensitive to spring-time drought. [31]

30 RH Schlegel, (2013) Rye: genetics, breeding, and cultivation. Crc Press.

31 H Domanska (1960) The influence of the autumn and spring drought on the development of winter rye and barley. Rocz Nauk Rolniczych. Ser A, 229–241.

Managing drought

Because drought events can be unpredictable and can last for extended periods of unknown length, it is difficult to prepare for them.

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:

- mental and physical energy to do the continuous tasks required;
- funds available;
- stock and domestic water available;
- surface/subsoil moisture for crop leaf and root growth;
- need to service machinery – breakdowns cost time, money and frustration.

Audit sheets are provided on the following pages to assist in guiding you through the resource audit.

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. [32]

MORE INFORMATION

Drought planning

Soil management following drought

Herbicide residues after drought

Winter cropping following drought

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. [33]

14.3.2 Heat stress

Key points:

- Heat stress is a key yield limiting factor in crop production.

32 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

33 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

- Heat stress has been shown to adversely affect yield as early as growth stage 45.
- Delayed sowing increases the chance of the crop being exposed to heat stress, particularly at the vulnerable pre-flowering growth stages.

Heat is a key abiotic stress. The effects of heat on grain yield are equally as important as drought and frost. Varieties that are better adapted also generally perform better in heat-stress conditions.

Rye is more sensitive to hot weather than oats and barley. [34]

The direct effects of heat stress are estimated to cost grain growers in south-east Australia almost $600 million per year and about $1.1 billion nationwide. 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. [35]

Heat-stress affects crop and cereal production in all regions of the Australian wheat belt. It can have significant effects on grain yield and productivity, with potential losses equal to, and potentially greater than, other abiotic stress such as drought and frost. Controlled environment studies have established that a 3–5% reduction in grain yield of wheat can occur for every 1°C increase in average temperature above 15°C. Field data suggest that yield losses can be 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.

The reproductive stages of growth have greater sensitivity to elevated temperatures, with physiological responses including premature leaf senescence, reduced photosynthetic rate, reduced seed set, reduced duration of grain-fill, and reduced grain size, all ultimately leading to reduced grain yield. Such elevated temperatures are a normal, largely unavoidable occurrence during the reproductive phase of Australian crops in September and October. [36]

In some cereals heat stress can be identified by the withering and splitting of leaf tips (Photo 12). Tips of the leaves can also turn brown to grey in colour. Some or all grains fail to develop in a panicle. [37]

34 A Clark (Ed.) (2007) Managing Cover Crops Profitably, 3rd ed. Sustainable Agriculture Network, Beltsville, MD, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

35 R Barr (2016) Diversity the key to balancing frost-heat risks, https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks

36 P Telfer, J Edwards, H Kuchel, J Reinheimer, D Bennett (2013) Heat stress tolerance of wheat. GRDC Update Papers 7 February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Heat-stress-tolerance-of-wheat

37 DAFWA. (2016). Diagnosing heat stress in oats. https://www.agric.wa.gov.au/mycrop/diagnosing-heat-stress-oats

Photo 12: *Withered and split tips in heat stressed cereal.*

Source: DAFWA

Managing heat stress

Key points:

- Choose varieties more tolerant to heat stress
- Sowing crops early may reduce the exposure to very hot conditions and heat stress.

Trials were conducted in South Australia in 2013 to test whether strategic sowing time and variety selection can reduce yield loss due to heat stress in wheat. The research suggests that variety selection and early sowing remain the most effective means to reduce the risk of a crop being damaged by excessive heat. A later sown crop will have an increased likelihood of being exposed to the heat stress at more sensitive growth stages, particularly pre-flowering, and will have greater consequences to the potential grain yield. [38]

MORE INFORMATION

Managing heat stress in wheat

14.3.3 Salinity

Water moves into plant roots by a process known as osmosis, which is controlled by the level of salts in the soil water and in the water contained in the plant. If the level of salts in the soil water is too high, water may flow from the plant roots back into the soil. This results in dehydration of the plant, causing yield decline or even death of the plant. Crop yield losses may occur even though the effects of salinity may not be obvious. The salt tolerance of a specific crop depends on its ability to extract water from salinised soils.

Salinity affects production in crops, pastures and trees by interfering with nitrogen uptake, reducing growth and stopping plant reproduction. Some ions (particularly chloride) are toxic to plants and as the concentration of these ions increases, the plant is poisoned and dies. [39]

Cereal Rye is thought to be relatively tolerant on saline soils, similar to barley, but will be affected in highly saline soils (8-16 ECe (dS/m)). [40]

38 Telfer P, Edwards J, Bennett D, Kuchel H. (2014). Managing heat stress in wheat. Australian Grain Technologies. http://www.msfp.org.au/wp-content/uploads/Managing-heat-stress-in-wheat.pdf

39 Queensland Government (2015) Impacts of salinity, https://www.qld.gov.au/environment/land/soil/salinity/impacts/

40 PIR.SA, Testing for soil and water salinity. Factsheet No:66/00.

IN FOCUS

How salinity affects the emergence, growth, yield and quality of rye

Researchers wanted to know how rye would respond to saline conditions. To find out, they conducted a two-year field study in the arid south-west of the USA, where some soils have become highly saline. They gave six salinity treatments to rye grown on a Holtville silty clay by irrigating with Colorado River water made artificially saline with sodium chloride (NaCl) and calcium chloride ($CaCl_2$) (1:1 by weight). The electrical conductivity of the irrigation waters were 1.1, 4.0, 8.0, 12.1, 16.0, and 20.1 dS/m–1 in the first year, and 1.1, 3.9, 7.5, 11.6, 15.6, and 19.8 dS/m–1 in the second year. The researchers measured vegetative growth and grain yield. Relative grain yield of two cultivars, Maton and Bonel, was unaffected up to a soil salinity of 11.4 dS/m–1 (electrical conductivity of the saturation extractKe). Each unit increase in salinity above 11.4 dS/m–1 reduced yield by 10.8%.

These results place rye in the salt-tolerant category.

The researchers found that both cultivars were slightly less salt tolerant during plant emergence than during subsequent stages of growth. (Seeds were planted in greenhouse sand cultures.) They found that straw yield was more sensitive to salinity than was grain yield. They attributed the reduction in yield primarily to reduced spike weight and individual seed weight, rather than to the number of spikes. They also found that bread quality decreased slightly with increasing levels of salinity. [41]

The arid climate and sandy soils of the Mallee render it readily susceptible to land-use change with the result that wind erosion and salinity are common outcomes of vegetation clearance. Dryland salting in the Mallee Region is a mixture of Primary and Secondary types; the former mainly occurring as evaporation salt pans or playas on broad flat plains while the latter has developed at the base of east-west dunes as a result of clearing of native vegetation causing rising ground-water and seepage. Continuous cropping and fallow management of interdune areas (swales) in the past have exacerbated the problem. [42]

Symptoms

What to look for in the paddock

- Moist bare patches where seed has failed to germinate or seedlings have died (Photo 13).
- Patches of stunted and apparently water stressed or prematurely dead plants in areas subject to salinity.
- Most crop weeds will also be affected with the exception of salt tolerant species.
- Salt crystals may occur on dry soil surface.

41 LE Francois, TJ Donovan, K Lorenz and EV Maas (1989) Salinity effects on rye grain yield, quality, vegetative growth, and emergence. Agronomy Journal. 81 (5), 707–712.

42 Victorian State Government (2015) Salinity in the Mallee region, http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/sss_salinity_mallee_region

Photo 13: *Bare saline area with surviving plants dying prematurely.*

Source: DAFWA

What to look for on plants

- Plants have a harsh droughted appearance, and may be smaller with smaller dull leaves (Photo 14).
- Old leaves develop dull yellow tips and die back from the tips and edge.
- Heads are smaller with small grain.
- Plants die prematurely.
- Root growth is reduced, and may be brown and poorly branched or die if the plant is also waterlogged.

Photo 14: *Surviving plants appear to be limp and water stressed.*

Source: DAFWA

Management strategies

The amount of crop yield reduction depends on such factors as crop growth, the salt content of the soil, climatic conditions, etc. In extreme cases where the concentration of salts in the root zone is very high, crop growth may be entirely prevented. To improve crop growth in such soils the excess salts must be removed from the root zone. The term reclamation of saline soils refers to the methods used to remove soluble salts from the root zone. Methods commonly adopted or proposed to accomplish this include the following:

Scraping:

Removing the salts that have accumulated on the soil surface by mechanical means has had only a limited success although many farmers have resorted to this procedure. Although this method might temporarily improve crop growth, the ultimate disposal of salts still poses a major problem.

Flushing:

Washing away the surface accumulated salts by flushing water over the surface is sometimes used to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from a soil is rather small, this method does not have much practical significance.

Leaching:

This is by far the most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of

MORE INFORMATION

Preventing and managing salinity

Managing saline soils

the area under reclamation. Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage; i.e. the ponded water drains without raising the water table. Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep. Leaching during the summer months is, as a rule, less effective because large quantities of water are lost by evaporation. The actual choice will however depend on the availability of water and other considerations. In some parts of India for example, leaching is best accomplished during the summer months because this is the time when the water table is deepest and the soil is dry. This is also the only time when large quantities of fresh water can be diverted for reclamation purposes. [43]

43 FAO. Saline soils and their management. http://www.fao.org/docrep/x5871e/x5871e04.htm

Marketing

Key messages

- Utilise the knowledge and resources provided by local grower groups.
- Know and understand key marketing principles:
- Expand the sales window
- You can't sell what you don't have
- Don't lock in a loss
- Don't be a forced seller
- If increasing production risk, take price risk off the table
- Separate the pricing decision from the delivery decision
- Sell valued commodities; not undervalued commodities
- Don't leave money on the table
- Read market signals
- Sell when there is buyer appetite
- Separate the delivery decision from the pricing decision

The final step in generating farm income is converting the tonnes of grain produced per hectare into dollars at the farm gate. This section provides best in-class marketing guidelines for managing price variability to protect income and cash flow.

MORE INFORMATION

Grain Marketing —2016

Grain marketing lingo—what does it all mean?

The psychology of grain marketing

15.1 Links to industry boards

The Cereal Rye Growers' Association industry body operated in the early 2000s. It was the industry's only representative body and in its time managed to achieve significant benefits for millers, processors and growers. Due to a lack of growers and funding, it has since closed. [1] However, rye growers can look to their local cereal grower groups for information and resources.

15.1.1 Mackillop Farm Management Group

Mackillop Farm Management Group develops and delivers innovative and sustainable farming practices through collaborative research, communication and extension for the benefit of members and the agricultural industry across the South East of South Australia, Western Victoria and beyond.

Objectives

1. To be the leading provider of Research, development and extension in the "region".
2. To drive adoption and innovation from R & D.
3. To support the development of independent research capabilities.
4. To be the leading organization representing mixed farming in the region.

These objectives are underpinned by two operational objectives.

1. Operate as a professional organisation.
2. To have a highly recognised and respected brand which delivers value to members.

1 ABC (2003) http://www.abc.net.au/site-archive/rural/sa/stories/s776029.htm

15.1.2 Riverine Plains

Riverine Plains Inc. is a not for profit, farming systems research and extension organisation that services cropping and mixed farmers in north-east Victoria and southern NSW.

Riverine Plains Inc. has a membership base of over 315 farming families spread across a wide geographical area. Members farm as far north as Lockhart and Henty in NSW, and as far south as Euroa and Shepparton in Victoria. The majority of members are dryland farmers, though a number also have access to irrigation.

The geographical area Riverine Plains Inc. services is known as the Riverine Plain, and it is from this that the group takes its name.

15.1.3 Southern Farming Systems (SFS)

Southern Farming Systems (SFS) is a farm driven, non-profit organisation helping higher rainfall farmers with practical research and information that produces sustainable results.

In 1995 the six founding members of (SFS) got together to find ways of making farming in the higher rainfall zone more profitable. Their problems were often different from those faced by farmers in other areas and different solutions would be required.

They set out to help themselves and in so doing created an organisation that now boasts 600 members in five branches across two states. It maintains international affiliations and has a strong link with the Foundation for Arable Research in New Zealand.

The success of (SFS) comes from strict adherence to the vision and objectives established by those pioneers. Its focus is totally on the higher rainfall zone. All research is of a practical nature and designed to produce long-term solutions to farmers.

It provides a network for its members to share ideas and experiences. Strong partnerships have been established with research and extension agencies, and agribusiness. These partnerships are hugely beneficial, but at all times Southern Farming Systems remains an independent provider of quality information.

Early members saw control of waterlogging in cropping paddocks as critically important. They felt it would give the greatest return in the short term and decided to concentrate resources on this problem.

The result was the adaptation of raised bed technology to broadacre cropping. This system has been implemented across approximately 70,000 ha of the higher rainfall zone, contributing to improved crop yields and farm profitability. [2]

15.1.4 Tasmanian Farmers and Graziers Association (TFGA)

Those who work within this vibrant industry require a strong bond and sound representation. These are the strengths of the Tasmanian Farmers and Graziers Association (TFGA), the state's peak agricultural body.

The TFGA represents big and small farms, making no distinction among farms or farmers. The TFGA's role is to provide a single, strong voice to deal with governments at all levels and with other industry bodies. Their prime aim is to ensure that the agricultural base of the state remains competitive and profitable.

The TFGA is committed to promoting the vital contribution the agricultural sector makes to Tasmania's environmental, social and economic fabric.

2 Southern Farming Systems, http://www.sfs.org.au/what-we-do

Operationally, the TFGA is divided into separate councils that deal with each of the major commodity areas: meat, wool, dairy, vegetables and other agriculture. Those commodity councils meet regularly on a statewide basis. Each has a voice on the board of the TFGA. As well, standing committees deal with cross-commodity issues such as climate change, biosecurity, water and weeds.

Farming is a traditional enterprise that also has to be as modern as tomorrow. In a country with such diverse climatic and geographical challenges as Australia's, the technology to improve farming practices has to be both up-to-date and evolving. Part of the TFGA's charter is to keep its members informed, using modern communications. [3]

15.1.5 Mallee Sustainable Farming (MSF)

Mallee Sustainable Farming (MSF) Inc. is a farmer driven organisation delivering research and extension services to the less than 350 mm rainfall Mallee cropping regions of New South Wales, Victoria and South Australia. MSF operates within a region of over four million hectares, extending beyond Balranald in the east to Murray Bridge in the west.

MSF formed in 1997 in response to a recognition that conservation farming practices had not been widely adopted across the region. Therefore, there was a need to identify the issues restricting the adoption of technology that would enhance the development of profitable and sustainable farming systems.

Since it was formed, MSF has achieved a great deal. Increases in farm profitability have been observed as a result of MSF activities, along with environmental and social gains. MSF continues to be guided by farmer members to meet their information needs, whether in the sphere of cereal cropping or livestock management. [4]

15.1.6 Hart Field Site SA

Hart is South Australia's premier agronomic field site, managed by farmers to provide independent information and skills to the industry.

Since 1982, the Hart Field Site Group has been conducting cropping trials at Hart in the Mid-North of SA. These trials are focussed on being relevant to the broad-acre farming community and are conducted independently. The substantial trials site at Hart is available for inspection throughout each growing season at Hart Crop Walks and Field Days and for student / farming group tours by appointment. Results are published each year in the comprehensive Trials Results book. Hart also facilitate various seminars and workshops. [5]

15.1.7 Birchop Cropping Group

The Birchop Cropping Group Inc. (BCG) improves the prosperity of Australian broadacre farmers through applied science-based research and extension. Birchip Cropping Group Inc. (BCG) is a not-for-profit agricultural research and extension organisation led by farmers from the Wimmera and Mallee regions of Victoria. Recognised both nationally and internationally by the industry as a credible, independent and innovative organisation, BCG's research and communication activities provide evidence, support and tools for improving farm management practices and profitability. [6]

15.1.8 Victorian No-Till Farming Association

The Victorian No-Till Farmers Association is a leading voice in south-east Australia for the use of no-till farming systems. The association started in 2002 after a small group of Wimmera farmers joined forces to discuss the benefits they were seeing using

3 Tasmanian Farmers and Graziers Association, http://www.tfga.com.au/

4 Malle Sustainable Farming Inc., http://www.msfp.org.au/

5 Hart Field Site Group, http://www.hartfieldsite.org.au/

6 Birchip Cropping Group Inc., http://www.bcg.org.au/

no-till farming techniques. The group's success quickly spread and Vic No-Till went from strength to strength as more farmers saw the benefits of no-till and zero-tillage farming.

The no-till farming pioneers in Victoria paved the way for the next generation who have a thirst for knowledge and farm improvement. Vic No-Till's farmers are implementing soil health principles to build the robustness and resilience of their farming systems. No-Till and retained stubble retention farming systems are not only environmentally sustainable, they are profitable and they produce a product that is nutrient dense.

Vic No-Till has had more than a decade's experience questioning farmers on what they want, tackling tough issues and delivering no-till farming events, such as demonstrations, crop walks and conferences. The association prides itself on being a valuable education and mentoring resource for farmers in Victoria, and the fact that growers can leave Vic No-Till's events and immediately implement the ideas they take away with them.

Vic No-Till is always looking for new members—sign up at their website. [7]

15.1.9 South Australian No Till Farming Association (SANTFA)

SA No Till Farming Association (SANTFA) continues to grow in size and scale as an influential organisation that provides high quality, challenging information on no-till systems. (SANTFA) is working to build their project work, business structures and human resources into a dynamic and exciting organisation. (SANTFA) will remain farmer based, farmer driven and fiercely independent.

(SANTFA) works to increase the area of no-till and to attract new supporters to conservation farming. (SANTFA) is committed to no-till systems and to pushing the limits on equipment design and system advances, and will conduct and coordinate independent research through a range of contractors. However, the association recognises that they are part of a wider farming systems focus in many regions. In this context, they will seek to be a significant influence on research conducted by others, and take care not to duplicate the activities of existing Farming Systems Groups.

(SANTFA) will provide education and information for growers being introduced to no-till as well as growers who require advanced support. In both cases, the association will continue to focus on options that enable members to meet the triple bottom line outcomes of economic, environmental and social sustainability.

15.2 Selling principles

The aim of a selling program is to achieve a profitable average price (the target price) across the entire business. This requires managing several factors that are difficult to quantify to establish the target price and then working towards achieving that target price.

These factors include the amount of grain available to sell (production variability), the final cost of that production, and the future prices that may result. Australian farm-gate prices are subject to volatility caused by a range of global factors that are beyond our control and difficult to predict.

The skills that growers have developed to manage variability and costs can be used to manage and overcome price uncertainty.

15.2.1 Be prepared

Being prepared and having a selling plan are essential for managing uncertainty. The steps involved are forming a selling strategy, and having a plan for effective execution of sales. A selling strategy consists of when and how to sell.

7 Victorian No-Till Farming Association, http://www.vicnotill.com.au/

Expand the sales window

By expanding the period in which growers can make grain sales, they are able to capture price opportunities in volatility observed year to year and achieve higher overall returns.

When to sell

This requires an understanding of the farm's internal business factors including:

- Production risk.
- A target price based on cost of production and a desired profit margin.
- Business cash-flow requirements.

How to sell?

This depends more on external market factors including:

- Time of year, which determines the pricing method.
- Market access, which determines where to sell.
- Relative value, which determines what to sell.

The key selling principles when considering sales during the growing season are described in Figure 1.

Figure 1: *Grower commodity selling-principles timeline. The illustration demonstrates the key selling principles throughout the production cycle of the crop.*

Source: Profarmer Australia

15.2.2 Establishing the business risk profile—when to sell

Establishing your business risk profile allows the development of target price ranges for each commodity and provides confidence to sell when the opportunity arises. Typical business circumstances of a cropping enterprise, and how the risks may be quantified during the production cycle, are described in Figure 2.

When does a growers sell their grain?

This decision is dependent on:

- Does the production risk allow sales? And what proportion of production?
- Is the price profitable?
- Are business cash requirements being met?

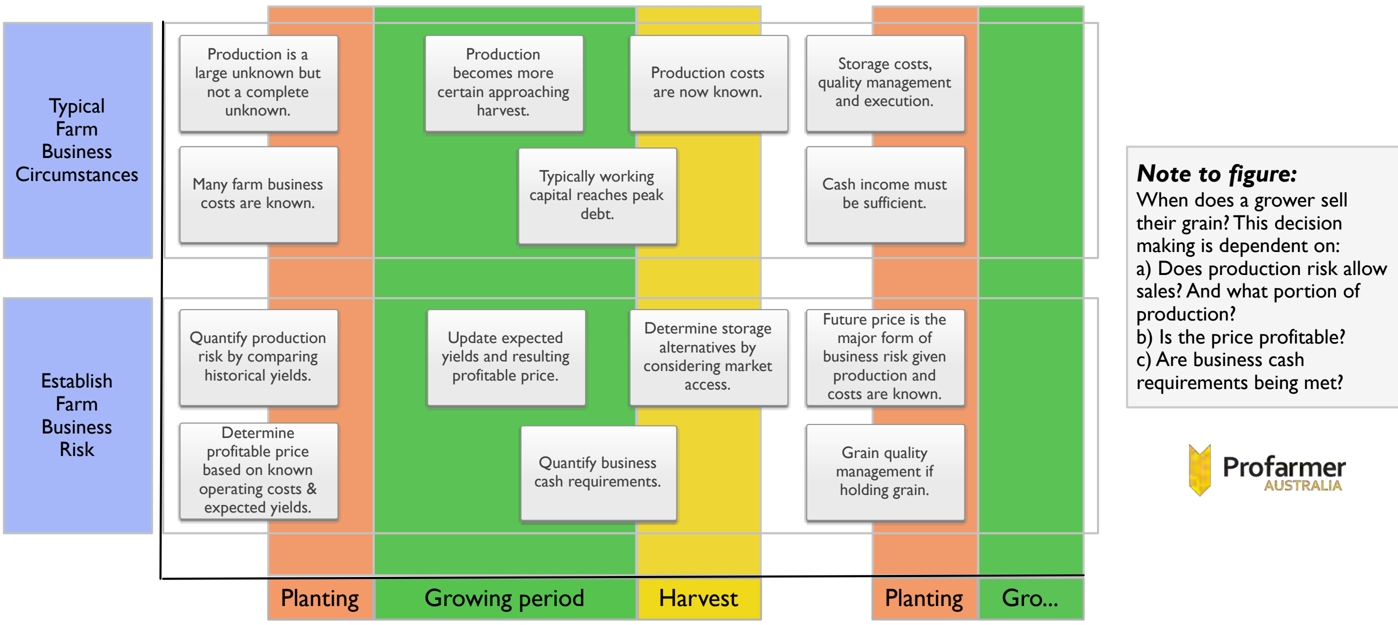


Figure 2: *Typical farm business circumstances and risk.*

Source: Profarmer Australia

15.2.3 Production risk profile of the farm

Production risk is the level of certainty around producing a crop and is influenced by location (climate and soil type), crop type, crop management, and time of the year.

You can't sell what you don't have

Do not increase business risk by overcommitting production.

Establish a production risk profile (Figure 3) by:

- Collating historical average yields for each crop type and a below-average and above-average range.
- Assessing the likelihood of achieving average based on recent seasonal conditions and seasonal outlook.
- Revising production outlooks as the season progresses..

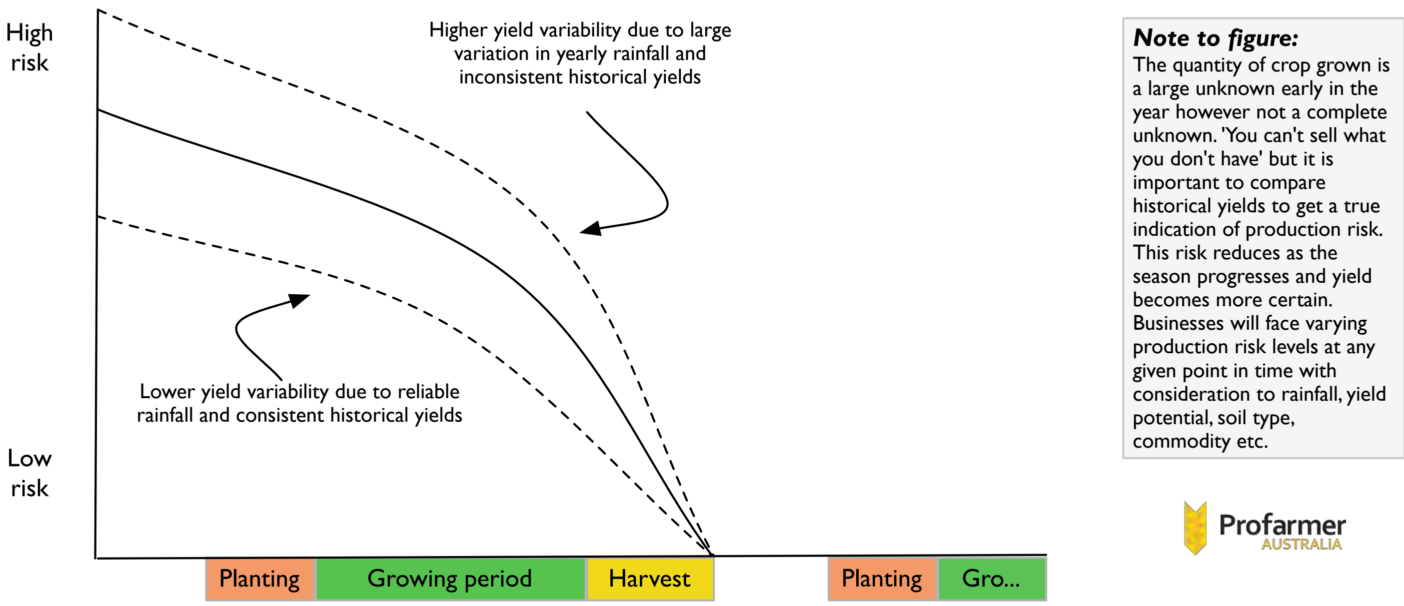


Figure 3: *Typical production risk profile of a farm operation.*

Source: Profarmer Australia

The quantity of crop grown is a large unknown early in the year, however not a complete unknown. “You can't sell what you don't have” but it is important to compare historical yields to get a true indication of production risk. This risk reduces as the season progresses and yield becomes more certain. Businesses will face varying production risk levels at any given point in time with consideration to rainfall, yield potential, soil type, commodity etc.

15.2.4 Farm costs in their entirety, variable and fixed costs (establishing a target price)

A profitable commodity target price is the cost of production per tonne plus a desired profit margin. It is essential to know the cost of production per tonne for the farm business.

Don’t lock in a loss

If committing production ahead of harvest, ensure that the price is profitable.

Steps to calculate an estimated profitable price based on total cost of production and a range of yield scenarios are provided in Figure 4.

Estimating cost of production - Wheat	
Planted Area	1,200 ha
Estimate Yield	2.85 t/ha
Estimated Production	3,420 t
Fixed costs	
Insurance and General Expenses	$100,000
Finance	$80,000
Depreciation/Capital Replacement	$70,000
Drawings	$60,000
Other	$30,000
Variable costs	
Seed and sowing	$48,000
Fertiliser and application	$156,000
Herbicide and application	$78,000
Insect/fungicide and application	$36,000
Harvest costs	$48,000
Crop insurance	$18,000
Total fixed and variable costs	$724,000
Per Tonne Equivalent (Total costs + Estimated production)	$212 /t
Per tonne costs	
Levies	$3 /t
Cartage	$12 /t
Freight to Port	$22 /t
Total per tonne costs	$37 /t
Cost of production Port track equiv	$248.70
Target profit (ie 20%)	$50.00
Target price (port equiv)	**$298.70**

Step 1: Estimate your production potential. The more uncertain your production is, the more conservative the yield estimate should be. As yield falls, your cost of production per tonne will rise.

Step 2: Attribute your fixed farm business costs. In this instance if 1,200 ha reflects 1/3 of the farm enterprise, we have attributed 1/3 fixed costs. There are a number of methods for doing this (see M Krause "Farming your Business") but the most important thing is that in the end all costs are accounted for.

Step 3: Calculate all the variable costs attributed to producing that crop. This can also be expressed as $ per ha x planted area.

Step 4: Add together fixed and variable costs and divide by estimated production

Step 5: Add on the "per tonne" costs like levies and freight.

Step 6: Add the "per tonne" costs to the fixed and variable per tonne costs calculated at step 4.

Step 7: Add a desired profit margin to arrive at the port equivalent target profitable price.

Figure 4: *Steps to calculate an estimated profitable price for grain.*

Source: Profarmer Australia

The GRDC Farming the Business manual also provides a cost-of production template and tips on skills required for grain selling, as opposed to grain marketing. [8]

15.2.5 Income requirements

Understanding farm business cash flow requirements and peak cash debt enables grain sales to be timed so that cash is available when required. This prevents having to sell grain below the target price to satisfy a need for cash.

Don't be a forced seller

Be ahead of cash requirements to avoid selling in unfavourable markets. Price variability also means growers who are not organised with their cash flow may risk becoming a forced seller in unfavourable markets.

VIDEOS

WATCH: 'Farming the Business' eBook resources.

8 M Krause (2014) Farming the business. Sowing for your future. GRDC, http://www.grdc.com.au/FarmingTheBusiness

As the market falls, growers need to sell greater volumes of grain in order to achieve the same cash flow outcome. This reduces their ability to capture any favourable price moves that may eventuate later in the season.

A typical cash flow to grow a crop is illustrated in Figure 5. Costs are incurred upfront and during the growing season, with peak working capital debt incurred at or before harvest. This will vary depending on circumstance and enterprise mix. Figure 6 demonstrates how managing sales can change the farm's cash balance.

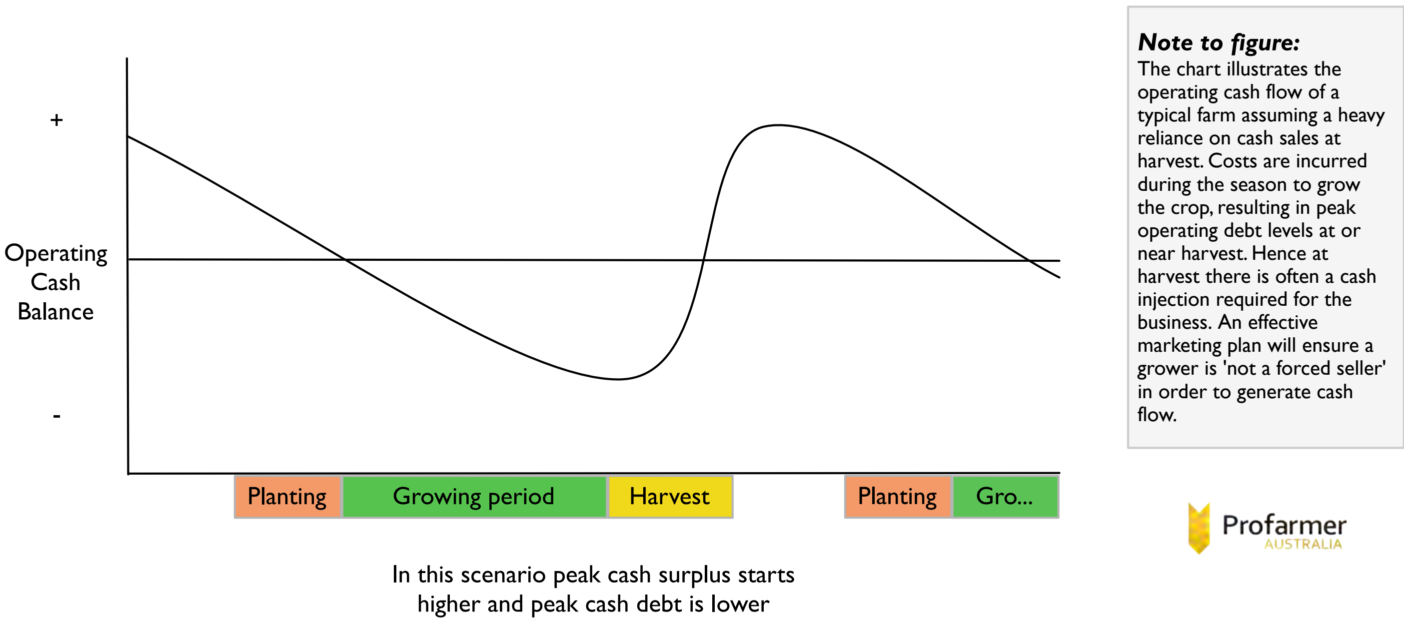


Figure 5: *Typical farm operating cash balance, assuming harvest cash sales. In this scenario, peak cash surplus starts higher and peak cash debt is lower.*

Source: Profarmer Australia

The chart above illustrates the operating cash flow of a typical farm assuming a heavy reliance on cash sales at harvest. Costs are incurred during the season to grow the crop, resulting in peak operating debt levels at or near harvest. Hence, at harvest there is often a cash injection required for the business. An effective marketing plan will ensure a grower is "not a forced seller" in order to generate cash flow.

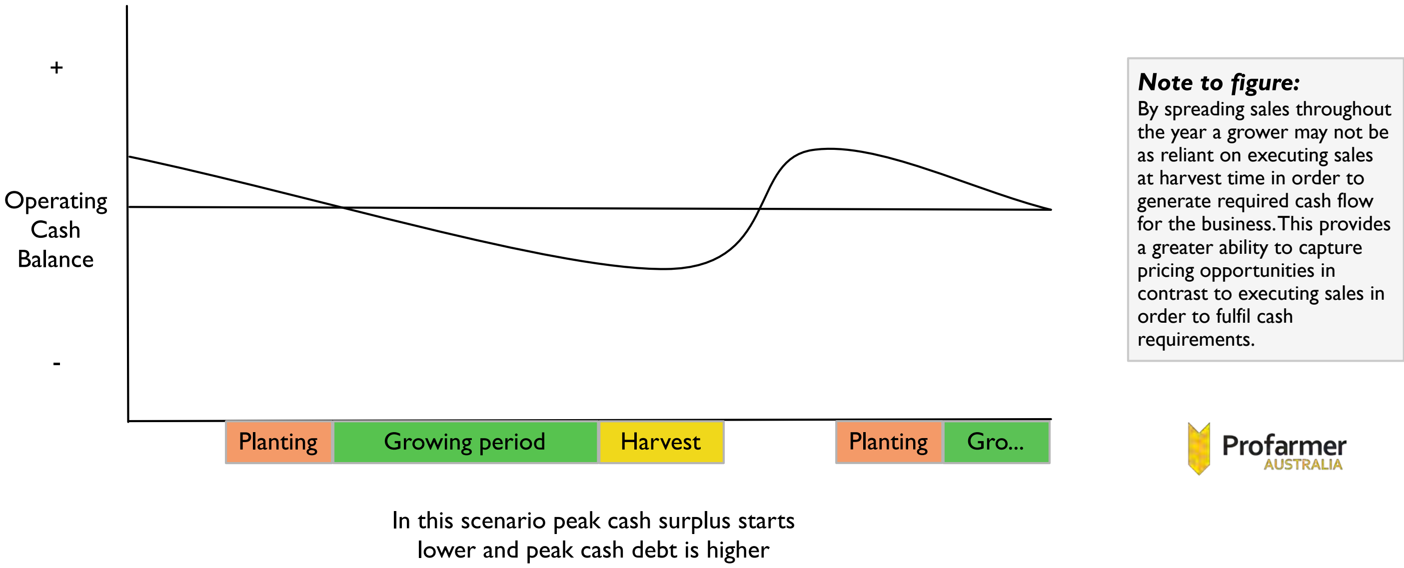


Figure 6: *Typical farm operating cash balance, with cash sales spread throughout the year. In this scenario, peak cash surplus starts lower and peak cash debt is higher.*

Source: Profarmer Australia

By spreading sales throughout the year, a grower may not be as reliant on executing sales at harvest time in order to generate required cash flow for the business. This provides a greater ability to capture pricing opportunities rather than selling in order to fulfil cash requirements.

Summary

These when-to-sell steps result in an estimated production tonnage and the risk associated with that tonnage, a target price range for each commodity, and the time of year when cash is most needed.

15.2.6 Managing your price—how to sell

This is the second part of the selling strategy.

Methods of price management

The pricing methods for products provide varying levels of price-risk coverage.

Figure 7 provides a summary of when different methods of price management are suited for the majority of farm businesses.

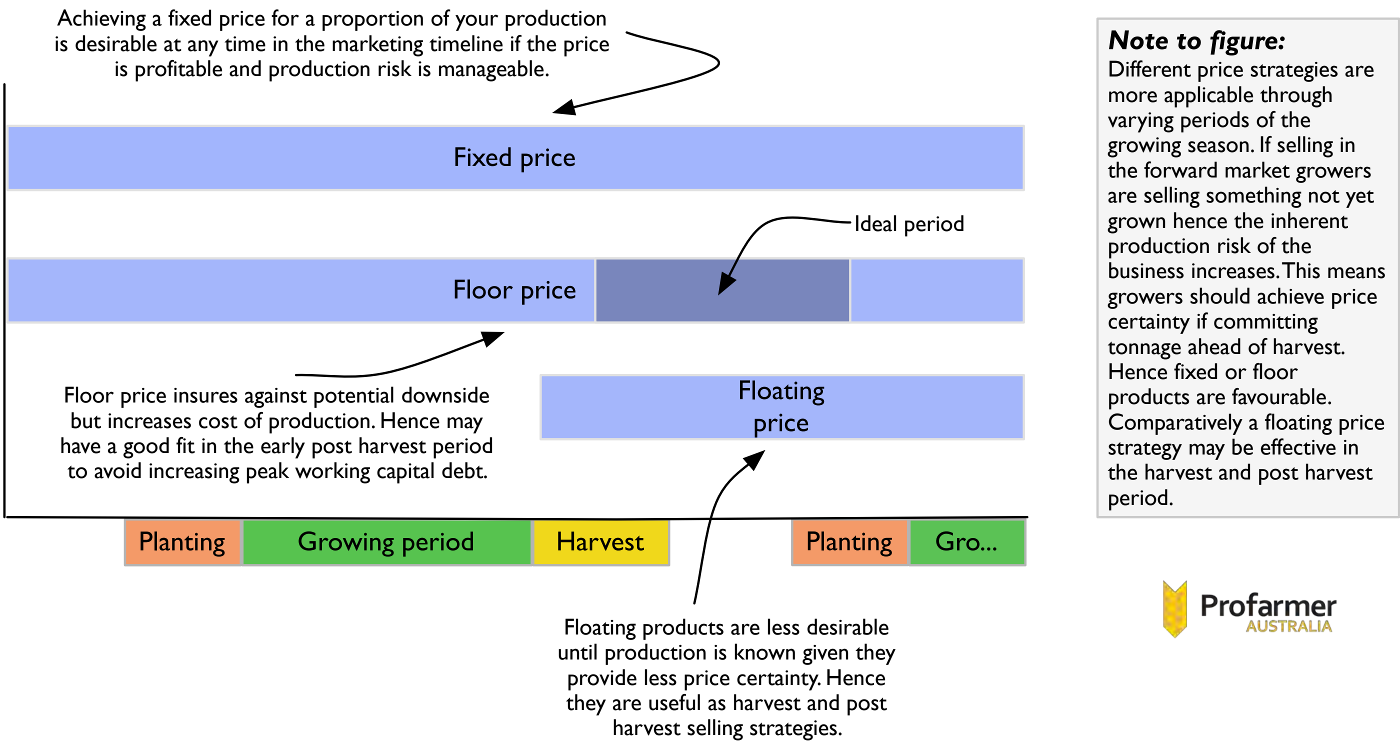


Figure 7: *Price strategy timeline through the growing season.*

Source: Profarmer Australia

Different price strategies are more applicable through varying periods of the growing season. If selling in the forward market growers are selling something not yet grown, hence the inherent production risk of the business increases. This means growers should achieve price certainty if committing tonnage ahead of harvest. Therefore fixed or floor products are favourable. Comparatively, a floating price strategy may be effective in the harvest and post-harvest period.

If increasing production risk, take price risk off the table

When committing unknown production, price certainty should be achieved to avoid increasing overall business risk.

Separate the pricing decision from the delivery decision

Most commodities can be sold at any time with negotiable delivery timeframes, so price management is not determined by delivery.

Fixed price

A fixed price is achieved via cash sales and/or selling a futures position (swaps) (Figure 8). A fixed price provides some certainty around expected revenue from a sale because the price is largely a known, except when there is a floating component in the price (e.g. a multi-grade cash contract with floating spreads or a floating basis component on futures positions).

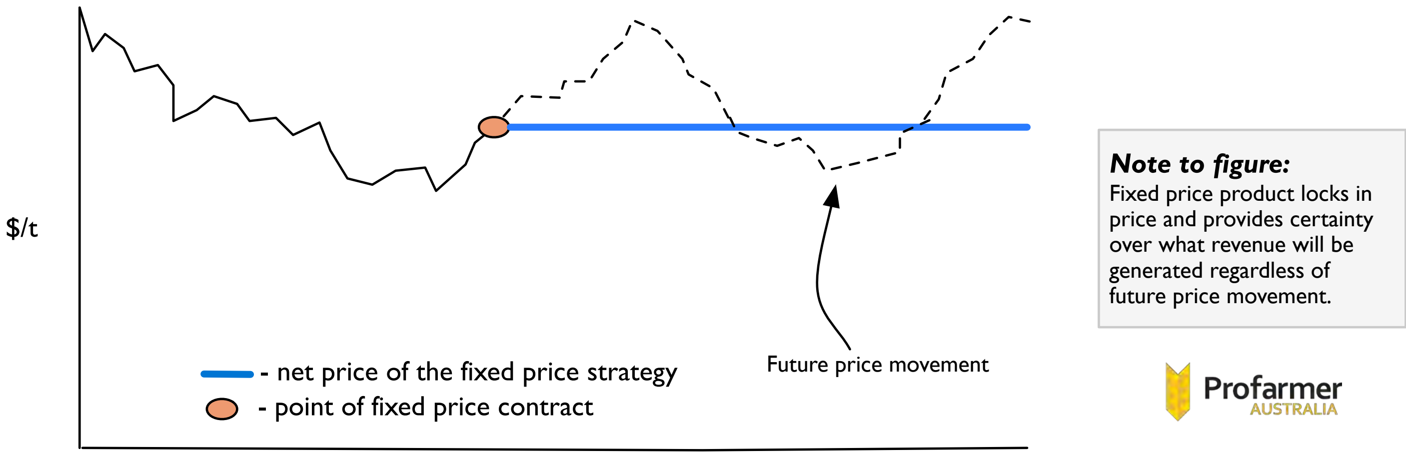


Figure 8: *Fixed price strategy.*

Source: Profarmer Australia

Fixed price provides certainty over what revenue will be generated regardless of future price movement.

Floor price

Floor price strategies can be achieved by utilising “options” on a relevant futures exchange (if one exists), or via a managed sales program product by a third party (i.e. a pool with a defined floor price strategy). This pricing method protects against potential future downside while capturing any upside (Figure 9). The disadvantage is that the price “insurance” has a cost, which adds to the farm business cost of production.

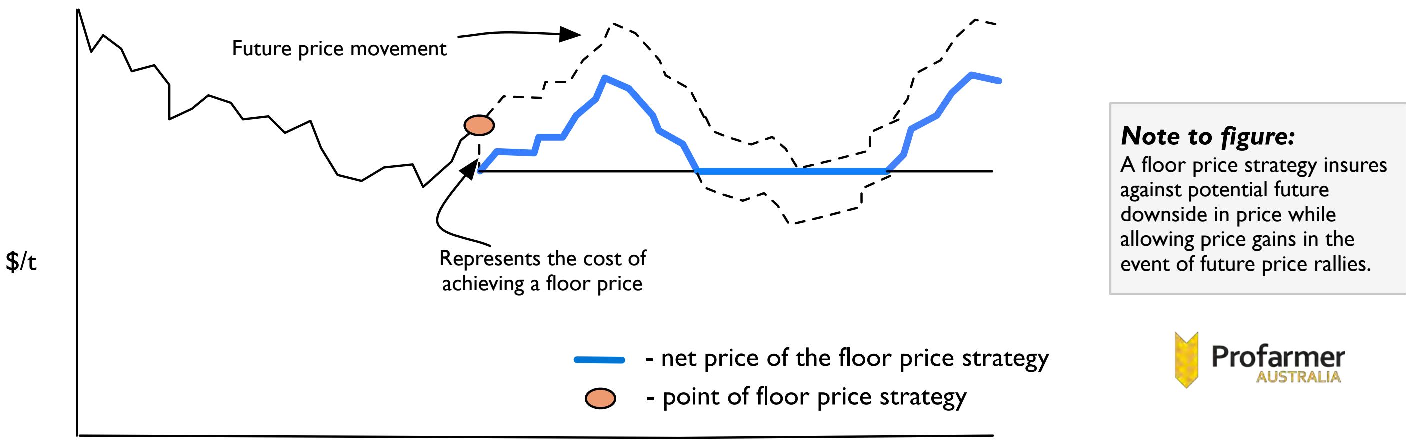


Figure 9: *Floor price strategy.*

Source: Profarmer Australia

A floor price strategy insures against potential future downside in price while allowing price gains in the event of future price rallies.

Floating price

Many of the pools or managed sales programs are a floating price, where the net price received will move both up and down with the future movement in price (Figure 10). Floating price products provide the least price certainty and are best suited for use at or after harvest rather than pre-harvest.

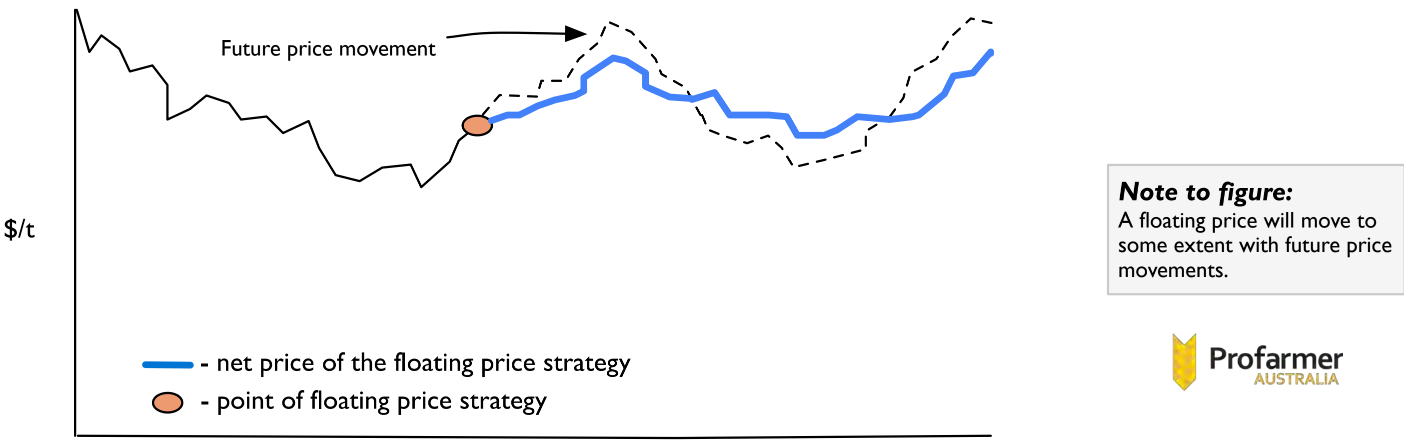


Figure 10: *Floating price strategy.*

Source: Profarmer Australia

A floating price will move to some extent with future price movements.

Summary

Fixed price strategies include physical cash sales or futures products and provide the most price certainty; however, production risk must be considered.

Floor price strategies include options or floor price pools. They provide a minimum price with upside potential and rely less on production certainty; however, they cost more.

Floating price strategies provide minimal price certainty and they are best used after harvest.

15.2.7 Ensuring access to markets

Once the selling strategy is organised, the storage and delivery of commodities must be planned to ensure timely access to markets and execution of sales. At some point, growers need to deliver the commodity to market. Planning on where to store the commodity is important in ensuring access to the market that is likely to yield the highest return (Figure 11).

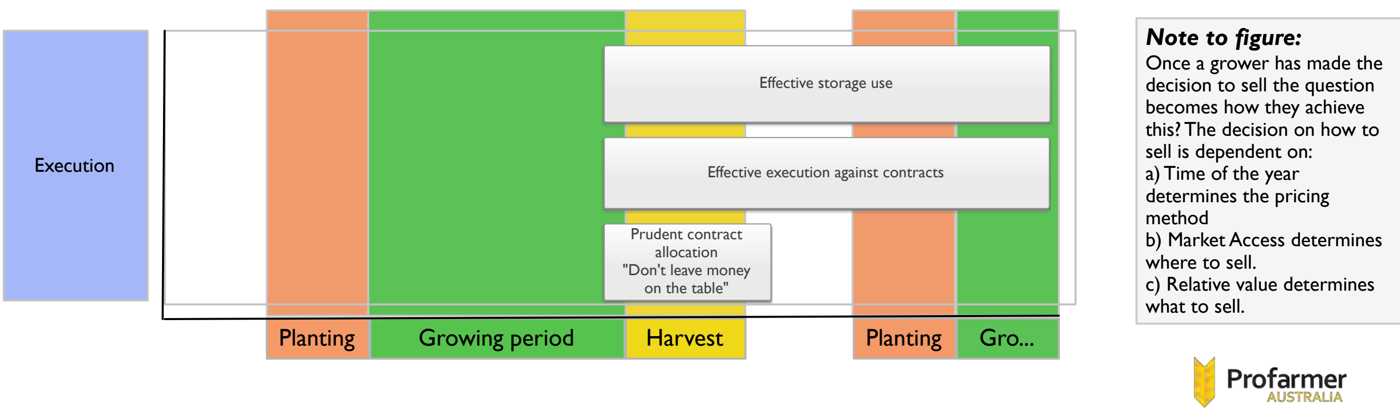


Figure 11: *Effective storage decisions.*

Source: Profarmer Australia

Once a grower has made the decision to sell, the question becomes how do they achieve this?

The decision on how to sell is dependent on the following:

- Time of the year determines the pricing method.
- Market Access determines where to sell.
- Relative value determines what to sell.

Storage and logistics

Return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access to maximise returns, as well as harvest logistics.

Storage alternatives include variations around the bulk handling system, private off-farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity (Figure 12).

Harvest is the first priority

Getting the crop into the bin is most critical to business success during harvest. Therefore, selling should be planned to allow focus on harvest.

Bulk export commodities requiring significant quality management are best suited to the bulk-handling system. Commodities destined for the domestic end-user market (e.g. feedlot, processor, or container packer) may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on-farm requires prudent quality management to ensure delivery at agreed specifications. Storing on-farm can expose the business to high risk if this aspect is not well planned. Penalties for out-of-specification grain on arrival at a buyer's weighbridge can be expensive. The buyer has no obligation to accept delivery of an out-of-specification load. This means that the grower may have to suffer the cost of taking the load elsewhere, while also potentially finding a new buyer. This will be costly for the business.

On-farm storage also requires prudent delivery management to ensure that the buyer receives commodities on time with appropriate weighbridge and sampling tickets.

Storage is all about market access

Storage decisions depend on quality management and expected markets.

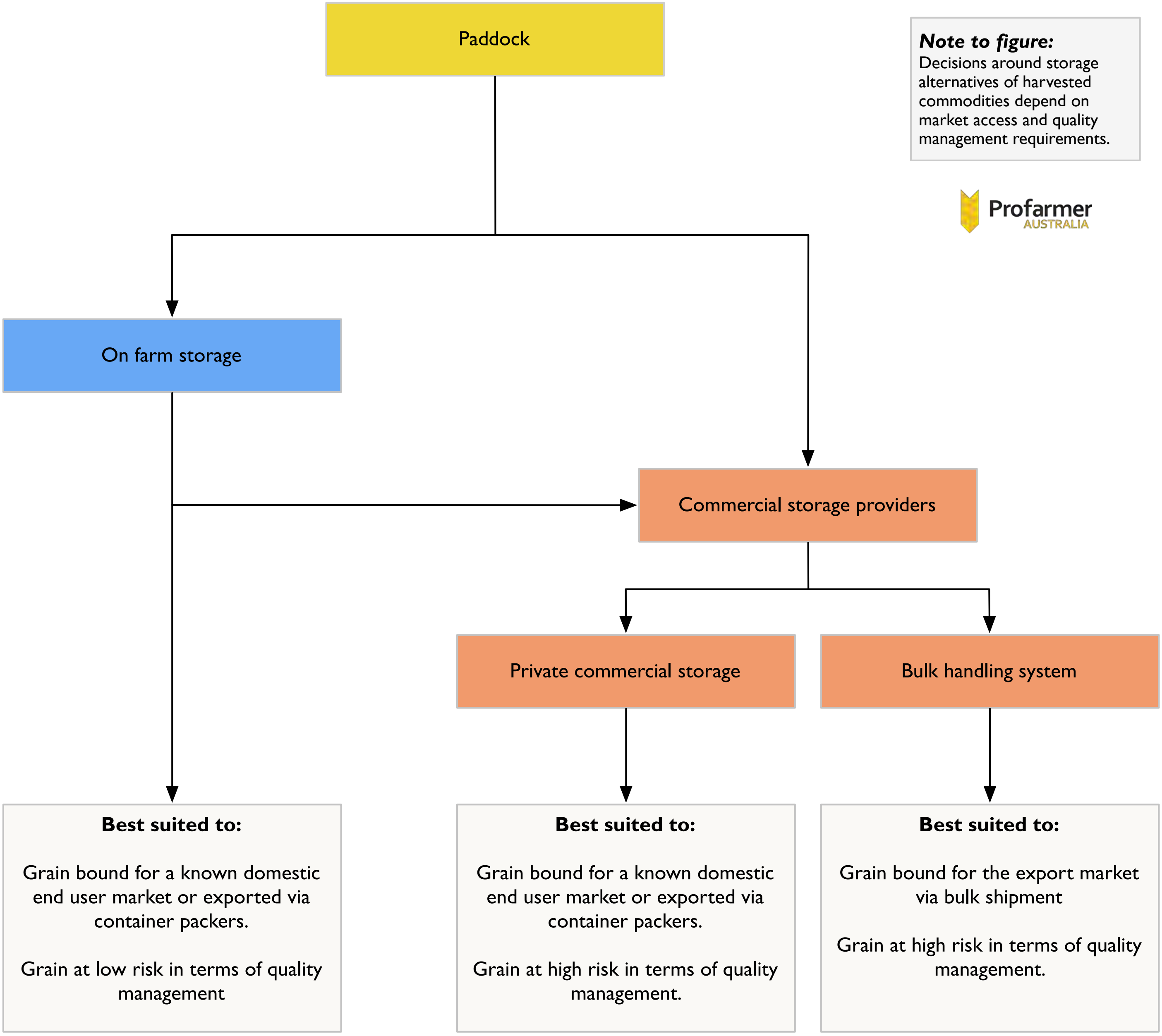


Figure 12: *Grain storage decision making.*

Source: Profarmer Australia

Decisions around storage alternatives of harvested commodities depend on market access and quality management requirements.

For more information about on-farm storage alternatives and economics, see Section 13: Storage.

Cost of carrying grain

Storing grain to access sales opportunities post-harvest invokes a cost to "carry" grain. Price targets for carried grain need to account for the cost of carry.

Carry costs per month are typically $3–$4/t, consisting of:

- monthly storage fee charged by a commercial provider (typically ~$1.50–$2.00/t); and
- monthly interest associated with having wealth tied up in grain rather than cash or against debt (~$1.50–$2.00/t, depending on the price of the commodity and interest rates).

The price of carried grain therefore needs to be $3–$4/t per month higher than was offered at harvest. The cost of carry applies to storing grain on-farm because there is a cost of capital invested in the farm storage plus the interest component. A reasonable assumption is $3–$4/t per month for on-farm storage.

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. If selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract.

Summary

Optimising farm-gate returns involves planning the appropriate storage strategy for each commodity to improve market access and cover carry costs in pricing decisions.

15.2.8 Executing tonnes into cash

Below are guidelines for converting the selling and storage strategy into cash by effective execution of sales.

Set up the tool box

Selling opportunities can be captured when they arise by assembling the necessary tools in advance.

The toolbox includes:

1. Timely information. This is critical for awareness of selling opportunities and includes: market information provided by independent parties; effective price discovery including indicative bids, firm bids, and trade prices; and other market information pertinent to the particular commodity.
2. Professional services. Grain-selling professional service offerings and cost structures vary considerably. An effective grain-selling professional will put their clients' best interests first by not having conflicts of interest and by investing time in the relationship. Return on investment for the farm business through improved farm-gate prices is obtained by accessing timely information, greater market knowledge and greater market access from the professional service.
3. Futures account and bank swap facility. These accounts provide access to global futures markets. Hedging futures markets is not for everyone; however, strategies that utilise exchanges such as CBOT (Chicago Board of Trade) can add significant value.

> **MORE INFORMATION**
>
> Current financial members of Grain Trade Australia, including buyers, independent information providers, brokers, agents, and banks providing over-the-counter grain derivative products
>
> Commodity futures brokers

How to sell for cash

Like any market transaction, a cash grain transaction occurs when a bid by the buyer is matched by an offer from the seller.

Cash contracts are made up of the following components, with each component requiring a level of risk management (Figure 13):

- Price. Future price is largely unpredictable; hence, devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.
- Quantity and quality. When entering a cash contract, you are committing to delivery of the nominated amount of grain at the quality specified. Therefore, production and quality risk must be managed.
- Delivery terms. Timing of title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end users, it relies on prudent execution management to ensure delivery within the contracted period.
- Payment terms. In Australia, the traditional method of contracting requires title of grain to be transferred ahead of payment; hence, counterparty risk must be managed.

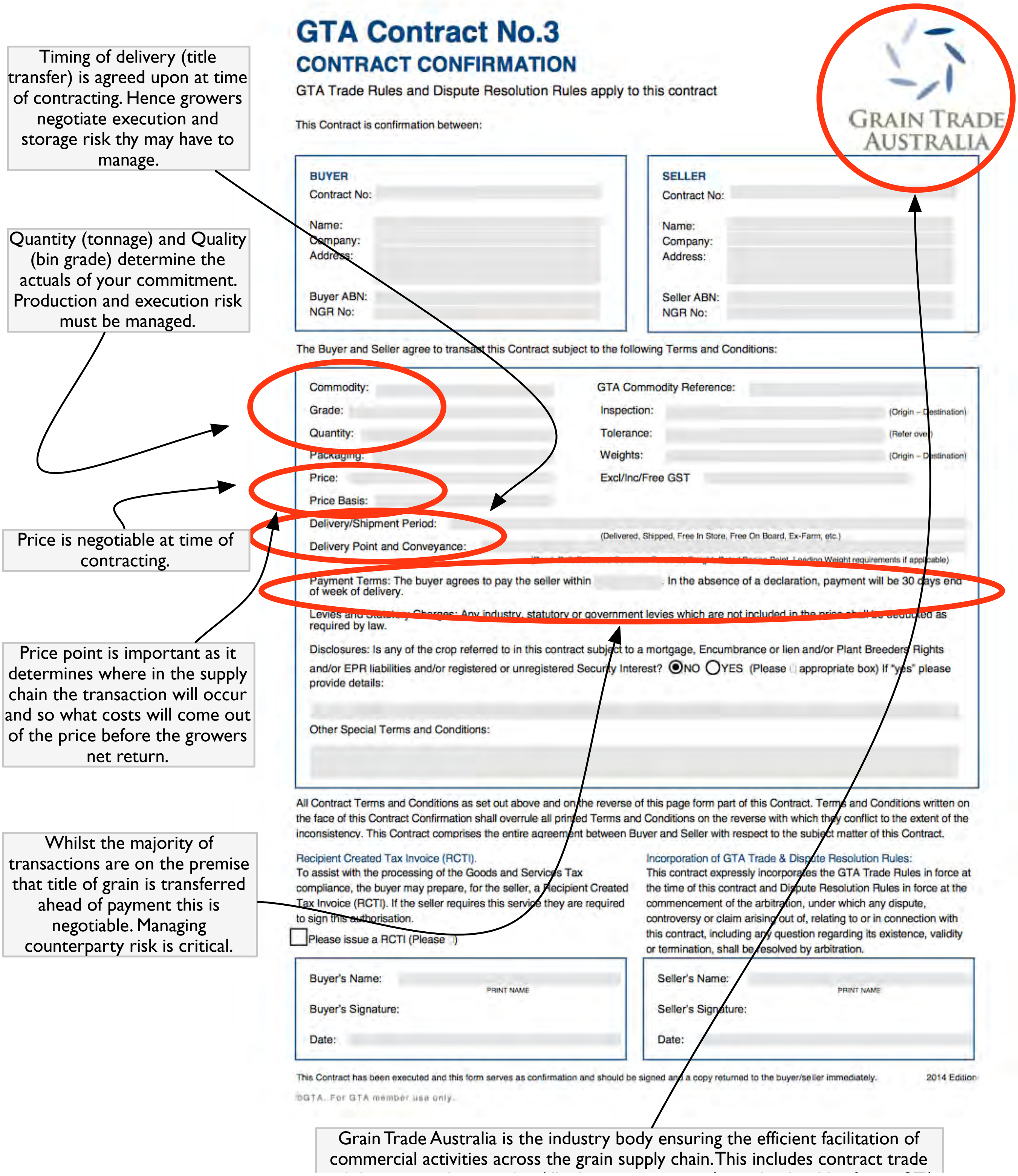


Figure 13: *Typical cash contracting as per Grain Trade Australia standards.*

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. Figure 14 shows the terminology used to describe pricing points along the grain supply chain and the associated costs to come out of each price before growers receive their net farm-gate return.

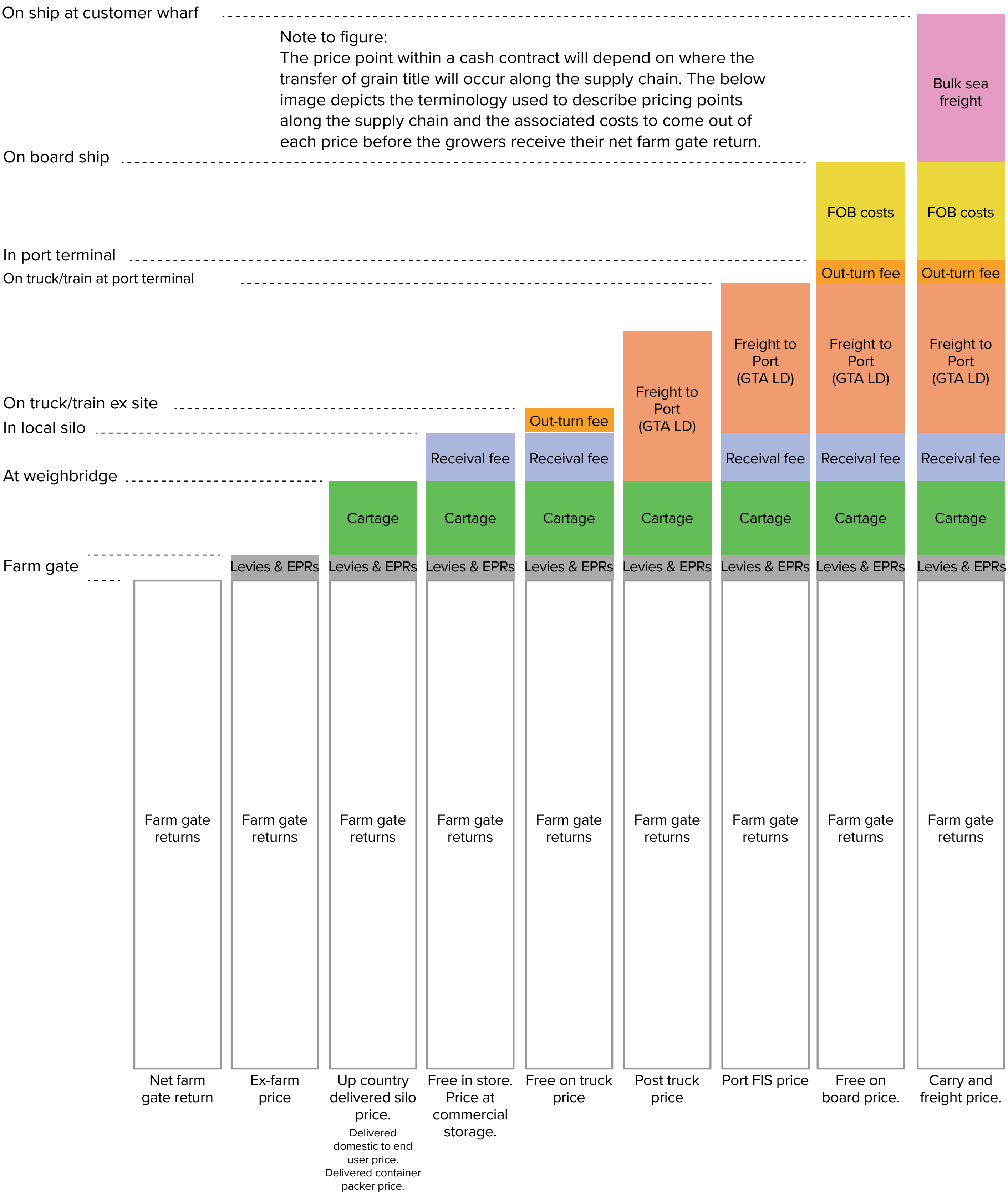


Figure 14: *Costs and pricing points throughout the supply chain.*

Cash sales generally occur through three methods:

1. Negotiation via personal contact. Traditionally, prices are posted as a "public indicative bid". The bid is then accepted or negotiated by a grower with the merchant or via an intermediary. This method is the most common and is available for all commodities.
2. Accepting a "public firm bid". Cash prices in the form of public firm bids are posted during harvest and for warehoused grain by merchants on a site basis. Growers can sell their parcel of grain immediately, by accepting the price on offer via an online facility and then transferring the grain online to the buyer. The availability of this depends on location and commodity.
3. Placing an "anonymous firm offer". Growers can place a firm offer price on a parcel of grain anonymously and expose it to the entire market of buyers, who then bid on it anonymously using the Clear Grain Exchange, which is an independent online exchange. If the firm offer and firm bid match, the parcel transacts via a secure settlement facility where title of grain does not transfer from the grower until funds are received from the buyer. The availability of this depends on location and commodity. Anonymous firm offers can also be placed to buyers by an intermediary acting on behalf of the grower. If the grain sells, the buyer and seller are disclosed to each counterparty.

Counterparty risk

Most sales involve transferring title of grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed.

Conducting business in a commercial and professional manner minimises this risk.

Seller beware

Selling for an extra $5/t is not a good deal if you do not get payment. Counterparty risk management includes the following principles:

- Deal only with known and trusted counterparties.
- Conduct a credit check (banks will do this) before dealing with a buyer you are unsure of.
- Sell only a small amount of grain to unknown counterparties.
- Consider credit insurance or letter of credit from the buyer.
- Never deliver a second load of grain if payment has not been received for the first.
- Do not part with title of grain before payment, or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting. Alternatively, the Clear Grain Exchange provides secure settlement whereby the grower maintains title of grain until payment is received from the buyer, and then title and payment are settled simultaneously.

Above all, act commercially to ensure that the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving $5/t more and not receiving payment is a disastrous outcome.

Relative values

Grain sales revenue is optimised when selling decisions are made in the context of the whole farming business. The aim is to sell each commodity when it is priced well and hold commodities that are not well priced at any given time; that is, give preference to the commodities of the highest relative value. This achieves price protection for the overall farm business revenue and enables more flexibility to a grower's selling program while achieving the business goals of reducing overall risk.

Sell valued commodities, not undervalued commodities

If one commodity is priced strongly relative to another, focus sales there. Do not sell the cheaper commodity for a discount.

Contract allocation

Contract allocation means choosing which contracts to allocate your grain against at delivery time. Different contracts will have different characteristics (price, premiums, discounts, oil bonuses, etc.), and optimising your allocation reflects immediately on your bottom line.

Don't leave money on the table.

Contract allocation decisions do not take long, and can be worth thousands of dollars to your bottom line.

To achieve the best average wheat price, growers should allocate:

- lower grades of wheat to contracts with the lowest discounts; and
- higher grades of wheat to contracts with the highest premiums.

Read market signals

The appetite of buyers to purchase a particular commodity will differ over time depending on market circumstances. Ideally, growers should aim to sell their commodity when buyer appetite is strong and should stand aside from the market when buyers are not as interested in buying the commodity.

Sell when there is buyer appetite

When buyers are chasing grain, growers have more market power to demand a price when selling. When buyer appetite is strong the seller has more ability to negotiate a better price.

Buyer appetite can be monitored by:

1. The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate buyer appetite is strong. However, if there is one buyer at $5/t above the next best bid, it may mean cash prices are susceptible to falling $5/t if that buyer satisfies their buying appetite.
2. Monitoring actual trades against public indicative bids. When trades are occurring above indicative public bids, it may indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids.

Summary

The selling strategy is converted to maximum business revenue by:

- Ensuring timely access to information, advice and trading facilities.
- Using different cash market mechanisms when appropriate.
- Minimising counterparty risk by effective due diligence.
- Understanding relative value and selling commodities when they are priced well.
- Thoughtful contract allocation.
- Reading market signals to extract value from the market or to prevent selling at a discount.

Separate the delivery decision from the pricing decision

Storage is all about market access—storage decisions depend on quality management and expected markets. Storage decisions are dependent on quality management and least cost pathways to expected markets. Alternatives include variations around the bulk handling system, private off farm storage, and on-farm storage. [9]

9 N Cattle, H Janson. Profarm, Putting a dollar value on best practice grain selling

15.3 Other relevant marketing issues

15.3.1 Improving structures around grain marketing decision making

Take home messages

- Good grain marketing can only occur if other aspects of the business are being managed appropriately to ensure there is choice in products and timing of sales.
- Understanding the different stages of the grain marketing process and optimising the length of the sales window are two key underlying frameworks for improving decision making.
- An overall decision making framework outlines the need for a foundation of good internal structure and an understanding of those factors that can be controlled within a business, and then overlaying good plans and strategies to deal with external factors that are outside your control.

Grain marketing can be viewed as a series of decisions that start with thinking about the market and carry through to ensuring sales are finalised, delivered on, and paid for. The result is cashflow; grain has been turned into cash, which can then be used for a number of things. Hence, a simplified definition of grain marketing is:

"A series of decisions and subsequent actions that turn grain into cashflow."

The ultimate aim is to maximise this cashflow by optimising yield and price given the constraints of any one season (both production and market constraints at the time). In terms of price, the single most important requirement is to have choice on when grain is sold. The idea behind price risk management is to create more pricing opportunities and manage them in a way that reduces overall risk, and doesn't just transfer one risk to another that can still impact the business. For example, reducing price risk if not done correctly can impact production risk.

There are three key concepts concerning grain marketing decision making:

1. the grain marketing process,
2. the grain marketing window, and;
3. the grain marketing pyramid.

These three concepts give a theoretical context to some of the more specific actions that can be undertaken to improve grain marketing outcomes.

Several grain marketing concepts have been introduced as ways to help build structure around the grain marketing decision making process. The theory behind the pyramid is that by building the foundation of a good internal structure then overlaying this with a strategy and a plan, and capping this off by good execution, an overall strong grain marketing process will result.

Rather than outlining specific actions, tools and resources, a general theory is outlined to help growers design their own pyramid in the way that suits their business. [10]

MORE INFORMATION

Improving structures around grain marketing decision making

15.3.2 Making effective grain marketing decisions—Eyre Peninsula

Take home messages

- Eyre Peninsula (EP) farmers in particular need to understand the impact of shipping on marketing.
- There is more to grain marketing than simply selling or brokering grain.
- There appears to be limited truth or accountability in advertising. The basic principle of "Buyer Beware" applies.

10 B Knight (2014) GRDC Update Papers: Improving structures around grain marketing decision making, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/09/Improving-structures-around-grain-marketing-decision-making

- In order to ensure the farming business' long term financial sustainability you need to make every effort to engage the market.
- There is a real cost for grain marketing to every business. This does not include the cost of getting it wrong.

The Eyre Peninsula market is unique:

- Limited domestic opportunities resulting in 100% export focus.
- Logistic closed loop with depreciated mobile and fixed infrastructure.
- Reliance on road, as many sites have no rail infrastructure. This results in additional political pressure from local councils.
- Geographic funnel with one of the best ports in Australia at the spout.
- Geographically isolated.
- Visionary medium term goals of linking a large capacity second port with potential mining industry infrastructure.
- Exporters want to and need to be active in this region.
- Access to shipping stems is providing a barrier to entry that is resulting in lower returns for producers.
- There is a culture within the EP farming community that is unique.

Whilst the EP is unique, in the context of global markets it is not special. If you export a commodity you need to think globally, and the world is rapidly shrinking. Just because you are geographically isolated you do not have to be isolated. Adoption of technology is the key. There is a significant cost for an exporter to have people on the ground. In order to compete in global markets, exporters naturally become focused on supply chain cost. [11]

MORE INFORMATION

Making effective marketing decisions

15.3.3 The grain industry in Tasmania—new and emerging markets

Take home messages

- Grain prices are likely to remain volatile.
- Set objective and realistic grain price targets for sales that fit business objectives.
- Increase economies of scale to spread fixed costs (storage and machinery costs).
- Consider new capital.

In 1842 Tasmania grew 48,000 ha of wheat, 52% of Australia's production.

In 1898 Tasmania produced around 100,000 mt of grain, 5% of Australia's production.

Today Tasmania produces around 60,000 mt of grain, 0.2% of Australia's production.

How to play in the modern markets

- Twelve months is a long time in grain markets: time, volatility and price.
- Set objective budgets and stick to them. Sell when it is good for your business, not when fear or greed tells you to.
- Manage how you sell your products: counterparty risk, quality risk and production risk.

Developing scale

- Tasmanian machinery costs are higher than similar rainfall and yield regions of Victoria: e.g. spray costs are $8–10/ha in Victoria versus almost $30/ha in Tasmania.
- Rationalising the number of gross margins: Victorian businesses may have 4–5 enterprises, Tasmanian businesses often have 10–15 enterprises. The question is, can you increase economies of scale and focus management resources?

11 C Heinjus (2013) GRDC Update Papers. Making effective grain marketing decisions, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Making-effective-grain-marketing-decisions

MORE INFORMATION

Grain marketing—The process, decisions and how to build a successful structure

Grain market update and underlying fundamentals—Does grain marketing really matter?

Be open to capital

- Capital expense on water (around $4,000/ha).
- Capital expense on water infrastructure (between 2–3,000/ha).
- Machinery and storage (around $1,000/ha).
- To convert water to product needs around $8,000/ha or $2 million to start to get scale.
- Take a lead from the dairy industry (especially in New Zealand) and look at equity partnership-type structures, which are now becoming more common in Australia and broadacre farming.

Summary

- Grain is not a new and emerging market; it is a resurrected market.
- There are huge opportunities in combining existing demand and water availability.
- Markets have changed; set a plan in place that lets you get on with producing.
- Don't over complicate the marketing and logistics component of the business at the end of the year.
- Increase economies of scale.
- Consider new capital. [12]

12 L Stevens (2015) The grain industry in Tasmania—new and emerging markets, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/The-grain-industry-in-Tasmania-new-and-emerging-markets

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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