Northern Region

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Oats

Northern Region

February 2016

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

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Start here for answers to your immediate oat crop management issues

Can I plant the same oat variety for grain, hay and grazing?

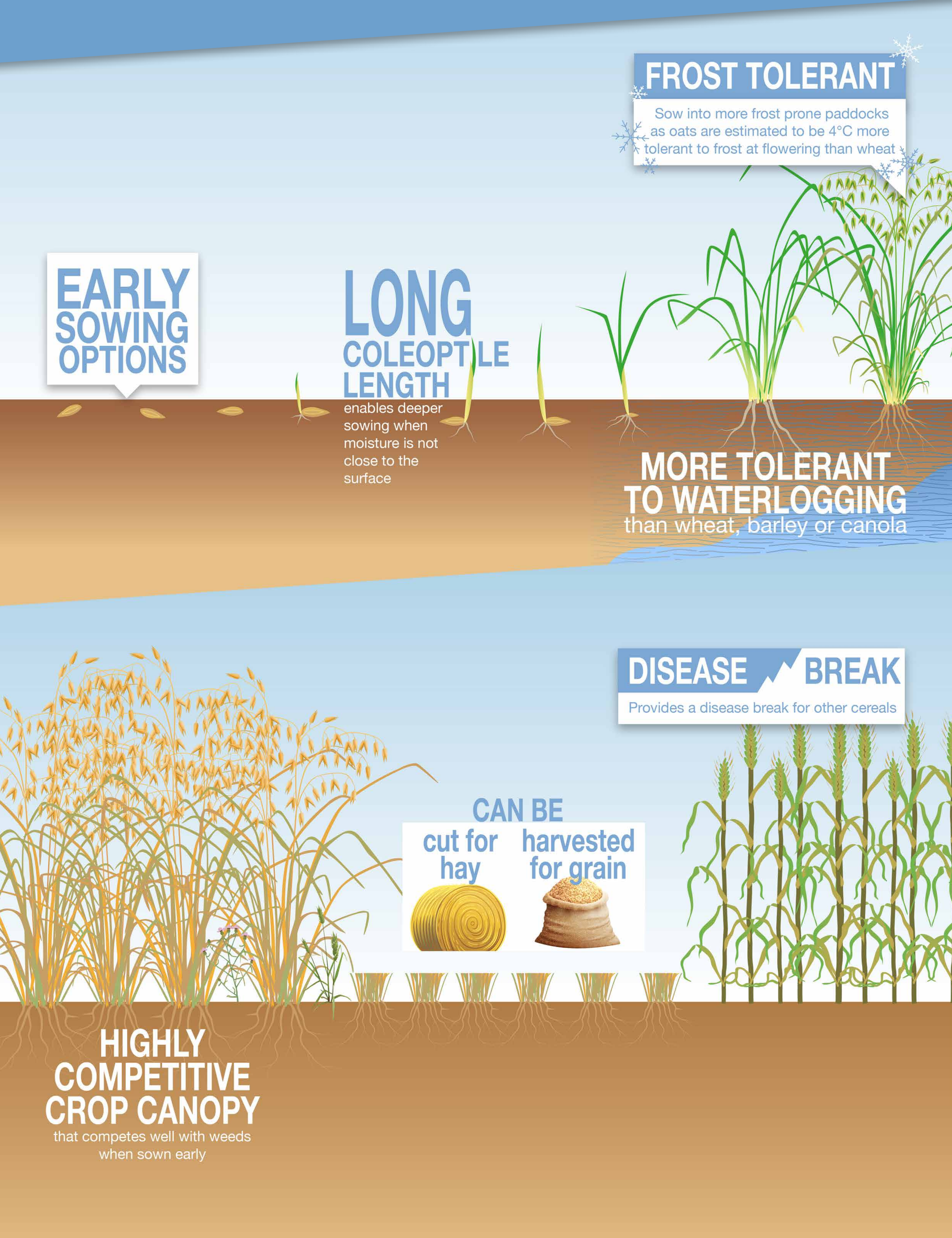
Is nutrition the same as other cereals?

What diseases are an issue in oats?

What is the grazing nutrition of oats compared to other cereals?

Do sowing rates differ between grazing, hay and grain production?

Benefits of oats in your rotation



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SECTION A

Introduction

Oats is the traditionally early sown winter cereal with many uses. As a dual purpose crop, oats can be used in the rotation for autumn or winter grazing if sown early enough, then locked up for grain if required.

It is frequently grown for grain and then stored on farm for stock feed or for human consumption. It can also be baled for hay.

Oats is adaptable to a wide range of soils and can tolerate some diseases that other cereals cannot. It can produce more forage than other cereals and has a higher winter growth rate than pastures.[1]

Figure 1: Oats for cattle feed. (Photo: GRDC)

This widely adapted and reliable cereal is a major winter cereal grazing crop. It also offers some rotational benefits where conditions are not suitable for broadleaf break crops. Oats can tolerate a range of cereal diseases such as take-all, crown rot and common root rot. The ease of establishment and early time of sowing are other major benefits. Its adaptability to acid soils, use for hay and silage, for pasture renovation, suitability for broadleaf weed control by in-crop herbicides, and usefulness for grazing-out make oats a versatile crop in farming systems.[2]

However its lower grain value means other dual purpose crops, such as winter wheats, will generally provide better returns.

1 NSW DPI (2008) Agriculture Today, Early start with oats http://www.dpi.nsw.gov.au/archive/agriculture-today-stories/ag-today-archives/march-2008/early-start-with-oats

2 NSW DPI Winter Crop Variety Sowing Guide 2015 http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

Grain oats are of minor importance in Queensland because of the limited grain varieties suited to the warmer growing conditions.[3] The importance of this crop expands as you head further south with it being commonly grown for grazing in the central west of NSW, in particular east of the Newell highway, and is common place in the farming systems of southern NSW.

Forage oats is the preferred winter forage crop for beef and dairy cattle in Queensland, due to its ability to produce good quality feed when most pastures are dormant.

Leaf rust is the most serious disease of forage oats, reducing yield, quality and palatability.[4]

A.1 Production

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, season and sowing time. Grain recovery and gross margins per hectare are not so clear-cut, with winter wheats and triticale often having yields comparable or better than those of oats, and, in the case of wheat, a more saleable grain come harvest .[5]

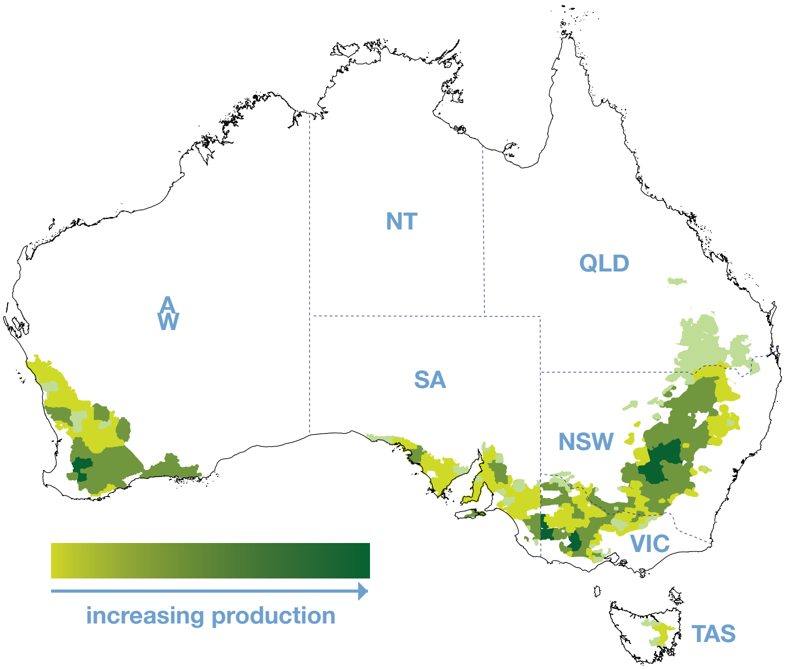


Figure 2: Areas of oat production. (Source: Australian Export Grains Innovation Centre)

AEGIC Australian Grain Note: Oats
http://www.aegic.org.au/media/23324/140214%20Oats%20Note.pdf

Australia produces on average 1.3 million tonnes of oats per year, with a large proportion processed domestically and up to 20% exported as grain. Australia is the fourth largest global exporter of oats after Canada, Finland and Sweden. Western Australia is the largest oat exporting state in Australia, and oats produced in New South Wales and Victoria are predominantly processed domestically.

3 DAF Qld (2002) Seed production https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/oats/seed-production

4 DAF Qld (2015) Forage oats variety guide https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

5 NSW DPI (2009) Primefacts Cereals for grazing http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/288191/Cereals-for-grazing.pdf

The ability of oats to withstand waterlogged conditions better than other cereals makes them well suited to cropping systems in high rainfall regions and on flood irrigation, particularly following rice.

A.2 Health benefits

Oat fibre has been shown to help reduce cholesterol and there is a growing promotion of oats as a health food—a movement that could help diversify market opportunities. For example, oats are being used in new Asian products, including oat noodles, oat milk and oat health-care products. [6]

[6] DAFWA (2015) Western Australian oat industry, https://www.agric.wa.gov.au/hay-production/western-australian-oat-industry

SECTION 1

Planning/Paddock preparation

More information

[GRDC NVT Crop Variety Guides]

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

Profit depends on choosing the most suitable variety for each end use, each paddock and matching this to the paddock's limitations, such as available moisture, diseases and nutrient status. Profitable yields result from good management, of which variety choice is only a minor part.

Paddock selection and rotation combined with use of disease-resistant varieties are the best actions to minimise disease. A table of disease ratings for current varieties can be found in the NSW Department of Primary Industries (DPI) Winter crop variety sowing guide and the Grains Research and Development Corporation (GRDC) Northern Variety Trials (NVT) Queensland Variety Guide. [1]

1.1 Paddock selection

Keys to good establishment:

- Use plump good quality seed from paddocks with a good fertiliser history and clean disease status, uniform in size, not cracked or broken, stored in dark cool dry conditions and free from pests and disease.
- Seed should have a high percentage germination, free from weed seeds and inert rubbish.
- Good soil-seed contact and 'sufficient' soil moisture for quick germination.
- No weeds should be present at sowing.

1.1.1 Paddock preparation

Paddock preparation for an oat paddock is identical to that of preparation for any other cereal crop. Weeds should be continually controlled over summer and soil maintained in as good a condition as possible, that is with little compaction or erosion issues.

Fallow weed control not only conserves nutrients and moisture for the following year's crop but also removes grass weeds that may act as a "green bridge" for some diseases to harbour on such as leaf and stem rust in oats.

There is a requirement by customers of the export hay market that hay be free of any contamination. Paddock preparation is a major part of management for export hay and requires:

- removal of old crop residues (burning)
- removal of sticks, tree branches, stones, carcasses, wire

[1] NSW DPI District Agronomists (2008) 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

- in some cases, rolling of paddocks[2]

Soil type

Soil characteristics (surface and subsurface) such as soil pH, sodicity, salinity, acidity, texture, drainage characteristics and compaction will affect variety selection. See the NVT Variety Guides for details of recommended varieties and planting times for individual districts within the northern region. For more detail see Section 2: Preplanting.

Subsoil moisture

Some crops are more expensive than others to grow due to input costs. Low levels of soil moisture at sowing can significantly increase financial risks. Paddocks with ground cover can retain moisture for longer, extending the time for planting after small rainfall events. Levels of starting soil water should also affect variety choice. Varieties with greater canopy size, such as late-maturing and/or very vegetative varieties, will generally require higher soil moisture levels to perform well.

Paddock nutrition

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

Herbicide history

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. For plant-back periods, see the NSW DPI publication Weed control in winter crops.

Weed burden

Identify your 'cleanest' paddocks and consider the use of pre-emergent herbicides. Some broadleaf weed species are difficult and/or expensive to control in pulse and oilseed crops. Risk may be reduced through the combination of pre-sowing weed knockdown, late-sown (early-maturing) crops/varieties and pre-harvest desiccation in crops where registration is current.

Weed management involves strategic herbicide applications in combination with other, non-chemical management options. Weed management in year 1 will affect the crop in year 2. If year 2 is a legume crop, more-vigilant control of broadleaf weeds in year 1's cereal may be a good strategic option.

Disease carryover

Crop sequencing is an important component of long-term farming systems and contributes to the management of soil N status, weeds, pests and diseases. Broadscale decisions on the sequence of crops include commodity prices, the short- and medium-term weather outlook, and the level of acceptable risk.

In the paddock, considerations include soil moisture levels before planting, current and desired stubble cover, history of herbicide use, history of diseases, and the population level(s) of RLN.

The GRDC northern region has seen significant adoption of summer and winter pulses in crop sequences for a variety of reasons, including improved soil N levels and management of crown rot in winter cereals.

For diseases, the focus in the GRDC northern region has been 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

[2] DAFWA (2014) Oats: seeding and establishment, https://www.agric.wa.gov.au/oats/oats-seeding-and-establishment

severity of major diseases of summer crops, especially those diseases that have several summer, and in some instances winter, crop hosts. See Table 1: Significant pathogens shared by different crops in the northern region. [3]

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

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.

Table 1: Significant pathogens shared by different crops in the northern region

Pathogen/ Nematode	Common name	Sorghum	Maize	Sunflower	Summer pulses	Cotton	Winter cereals	Winter pulses
Pratylenchus thornei	root-lesion nematode	-	-	-	✓✓ m,s	-	✓✓	✓✓ c,f
Pratylenchus neglectus	root-lesion nematode	✓✓				nt	✓✓	✓✓ c
Fusarium graminearum	head blight	✓	✓✓	-	-	-	✓✓	-
Macrophomina phaseolina	charcoal rot	✓✓	✓✓	✓✓	✓✓ m,s,g	✓	-	✓
Sclerotinia sclerotiorum, S. minor	sclerotinia rot	-	-	✓✓	✓✓ s,m,g	-	-	✓✓ c,f,p
Sclerotium rolfsii	basal rot	✓	✓	✓	✓✓ s,g	✓	-	-
Fusarium verticillioides	fusarium stalk and cob rot	✓	✓✓	-	-	-	-	-
Fusarium semitectum	fusarium head blight and stalk rot	✓✓	✓	-	-	-	-	-

✓✓ - major disease; ✓ - recorded but generally minor disease; c=chickpeas; f=fababean; g=peanut; m=mungbean; p=field pea; s=soybean; nt=not tested

Pests

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. For information on in-furrow treatment options see Section 3: Planting.

For line drawings of soil insects, visit: http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects/soil-insects.

For more information, see Section 3: Planting and Section 7: Insect control.

See also Australian Pesticides and Veterinary Medicines Authority Public Chemical Registration Information System (APVMA PubCRIS database) and NSW DPI Winter crop variety sowing guide websites.

[3] KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet, http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland

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

Fallow management

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

Timely weed control reduces moisture losses and weed seed set. Maintaining ground cover increases moisture conservation. Absence (or restriction) of grazing periods maintains soil friability and ground cover. Prolonged grazing periods may create crop emergence problems through induced surface compaction. [5]

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

Key points for control of the green bridge:

- Outright kill of the weeds and volunteers is the only certain way to avoid them 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 simultaneously eradicate weeds and crop volunteers.
- 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. [6]

1.2 Paddock rotation and history

Ensure the previous year's crop has had good grass weed management, as there are few grass weed control options available in an oat crop. This control can be via pasture manipulation or spray-topping in the previous pasture, diligent grass control in-crop the previous year or weed seed capture at harvest in a cropping situation to reduce weed seed numbers for the coming seasons crop. Grass control in the preceding grain legume or oilseed crop is essential to reduce diseases that may use grass weeds as hosts

Crop sequencing is a key part of a long-term farming systems approach to tackling weed, disease and moisture challenges in the northern grains region. Nitrogen-fixing summer and winter pulses are gaining popularity as cereal breaks.

The GRDC northern region has seen significant adoption of summer and winter pulses in crop sequences for a variety of reasons, including improved soil N levels and management of crown rot in winter cereals.

Paddock history should record chemicals applied to a paddock each year so appropriate withholding periods can be observed, fertilizers applied and a weed and disease audit conducted each year. Soil constraints of the paddock should also be considered when deciding on crop and variety options.

1.2.1 Soil pH/liming

Oats are relatively tolerant of acid soil, being more tolerant than wheat or barley.

Growth will be adversely affected when soil pH is below 5.3.[7]

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

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

7 Pacific Seeds (2006/07) Pacific Seeds Yearbook 2006/2007 - Oats Agronomy Guide, https://www.pacificseeds.com.au/images/stories/winter_forage/information/yearbookoatsagronomy2006.pdf

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

More definitive indications of acidic soil are:

- Stunted or shallow root growth in crops and pastures;
- Poor nodulation in legumes or ineffective nodules;
- Manganese toxicity symptoms in susceptible plants.

A soil test is the most reliable way to assess if soils are acidic.

Where soils are at risk of becoming acidic the future impact of soil acidity can be reduced, but not eliminated, by slowing the rate of acidification.

This can be achieved by:

- minimising leaching of nitrate nitrogen;
- using less acidifying fertilisers;
- reducing the effect of removal of product;
- preventing erosion of the surface soil.

Application of finely crushed limestone, or other liming material, is the only practical way to neutralise soil acidity. Limestone is most effective if sufficient is applied to raise the pHCa to 5.5 and it is well incorporated into the soil. Where acidity occurs deeper than the plough layer, the limestone will only neutralise subsurface soil acidity if the pHCa of the surface soil is maintained above 5.5.[8]

The economic benefits of lime

The benefits of lime prove to be not only economically significant but the consequence of improved soil quality and increased nutrient uptake makes cropping more sustainable. However, a liming scheme does not result in overnight success. The amelioration of acidified soils is a lengthy process but it is worthwhile in the retention of a healthy, vibrant and sustainable soil. The longer the beneficial effects of lime persist, the more the investment in liming becomes economically favourable.

Subsoil constraints such as acidity result in decreased rates of root elongation and limit the plant's ability to access water and nutrients. Subsoil acidity is caused by the excess application of acidic substances such as ammonium fertilisers. Surface liming is a common practice for ameliorating topsoil acidity in the relatively short-term, but is generally slow in ameliorating subsoil acidity.

When acidity is increased, important nutrients such as nitrogen and phosphorus are less available to plants whilst nutrients only needed in trace amounts such as aluminum and manganese are increased. This can lead to Aluminum and Manganese toxicity resulting in a dramatic decline of plant growth. Lime substantially reduces the level of exchangeable Al and exchangeable Mn whilst raising soil pH by about 1.0 unit. Liming soils can remove the toxicities of aluminum and manganese and, dependent on the extent of acidity and species, plants may differ in their response to soil amelioration with lime (3). A pH level of 5.5 is often seen as the optimum value for the growth of the plants.

Liming schemes are an appropriate solution to this problem and ensure the longevity of soils that may be succumbing to acidity. The long-term residual benefits of limestone

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

have been shown to extend for beyond 8-12 years and indicate that liming should be profitable in the long term.[9]

1.3 Benefits of crop as a rotation crop

- Early sowing options – helps spread out the work load at a busy time.
- Long coleoptile length – enables deeper sowing when moisture is not close to the surface.
- Dual purpose nature – can graze.
- Frost mitigation – sow into more frost prone paddocks as a more robust market for oaten hay if the paddock is unfortunate enough to be hit by frost.

In 2013, oats once again showed their tolerance to frost, compared with other cereals in some regions of Victoria and southern NSW.[10]

1.4 Disadvantages of crop as a rotation crop

- Limited option in grass weed control.
- A smaller range of in-crop broadleaf weed control chemicals.
- Still a cereal, so offers little disease break to diseases such as crown rot, CCN, take all etc.
- Can tend to want to shatter at harvest time.
- Lower yields than wheat and barley.
- inconsistent grain prices.

1.5 Fallow weed control

Controlling fallow weeds prior to sowing oats is important for retaining soil moisture and nitrogen levels and facilitates early sowing. Fallow weed control also removes the 'green bridge', reducing the survival of aphids and the risk of aphid transmitted viruses.

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

10 T Bray (2014) Irrigated milling oats set to roll. IREC Farmers' Newsletter – Large Area No. 190: Autumn 2014, http://irec.org.au/farmer_f/pdf_190/Milling-oat-opportunities-for-irrigators.pdf

Table 2: Herbicides for fallow commencement and/or maintenance – grass weed control

Rate per hectare Various trade names sometimes available under these concentrations. See specific labels for details.	Imazapic 240 g/L Flame® Pre-emergent	Paraquat 360 g/L Gramoxone® 360 Pro # Adjuvant required to be added at label rates for all applications	Paraquat + Diquat 135 + 115 g/L Spray.Seed® 250	Amitrole 250 g/L + Paraquat 125 g/L Alliance®	Glyphosate 570 g/L Roundup Ultra® Max	Glyphosate 540 g/L Weedmaster® Argo®	Glyphosate 470 g/L Weedmaster® DST®
Grass weeds	(litres)	(litres)	(litres)	(litres)	(litres)	(litres)	(litres)
annual phalaris	–	0.83 - 1.67	1.2–2.4	–	0.625–0.95	0.33–0.67	0.38–1.5
annual ryegrass	–	0.83 - 1.67	1.0–3.2	3.0–4.0	0.95–1.25	1.0–1.3 e	1.15–1.5
barley grass	–	0.83 - 1.67	1.0–3.2	3.0–4.0	0.625–0.95	0.33–1.0	0.38–1.5
barnyard grass	0.15–0.2	0.83 - 1.67	1.2–2.4	3.0–4.0	0.625–1.3	0.67–1.3	0.76–1.5
blowaway grass	0.15–0.2	–	–	–	–	–	–
brome grass	–	0.83 - 1.67	1.0–3.2	3.0–4.0	0.95–1.25	1.0–1.3	0.96–1.5
button grass	0.15–0.2	–	–	–	0.625–1.3	0.67–1.3	0.76–1.5
cereals – volunteer	–	0.83 - 1.67	1.0–3.2	3.0–4.0	0.625–0.95	0.33–1.0	0.38–1.5
couch	–	–	–	–	1.2–1.9 b	1.0–2.0 b	1.15–2.3 b
Johnson grass	–	–	–	–	1.2–1.9	1.3–2.0	1.15–2.3
liverseed grass	0.15–0.2	0.83 - 1.67	1.2–2.4	–	0.625–1.3	0.67–1.3	0.76–1.5
native millet	–	–	–	–	0.625–1.3	0.67–1.3	0.76–1.5
nut grass	–	–	–	–	1.9 + 1.9 c	2.0 + 2.0 c	2.3 + 2.3 c
phalaris – perennial	–	–	–	–	1.2–1.9	–	1.44–1.9
pigeon grass	–	–	–	–	–	–	–
sorghum – volunteer	–	–	–	–	0.425–1.3	0.67–1.3	0.76–1.5
spiny burrgrass	–	–	–	–	–	–	–
stinkgrass	0.15–0.2	–	1.2–2.4	–	0.425–1.3	0.67–1.3	0.76–1.5
summer grass	–	–	–	–	0.425–1.3	0.33–1.0	0.38–1.5
sweet summer grass	–	–	–	–	–	0.5–1.3	0.57–1.5
vulpia	–	0.83 - 1.67	1.0–3.2	–	0.95-1.25 a	1.0–1.3 e	1.15–1.5
wild oats	–	0.83 - 1.67	1.0–3.2	3.0–4.0	0.625–0.95	0.33–1.0	0.38–1.15
windmill grass	–	–	–	–	–	–	–
winter grass	–	0.83 - 1.67	–	–	0.95–1.25	–	0.96–1.5
Yorkshire fog	–	–	–	–	1.2–1.9	–	–
Rec. water vol L/ha boom	50 min	50–200	50–200	50–200	80 max	25–100	25–100
Wheat plant back	4 months	1 hr	1 hr	0 hr c	1 hr	6 hr	6 hr
Herbicide group	B	L	L	L + Q	M	M	M

Fallow residual pre-emergent herbicide. Apply to paddock at least 4 months before planting wheat, barley, chickpea. 200 mm rainfall required for plant-back.

a = When treating dense populations, use higher rate, add Wetter TX® and water volumes > 70 L/ha. b = Best in conjunction with multiple applications and/or cultivation.

c = See label for program.

e = Minimum water rate of 70 L/ha and appropriate nozzles. See label.

is a preferred option. READ LABEL BEFORE USE. REGISTERED CHEMICALS AS AT March 30, 2015

1.6 Fallow chemical plant-back effects

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

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods, (e.g. sulfonylureas (chlorsulfuron)). 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. [11]

Table 3: Guidelines for crop rotations – Fallow commencement/maintenance and presowing seedbed weed control

The following plant back periods are a guide only based on label recommendations. The time indicated between application and safe crop rotation intervals may depend on a range of factors including rainfall (amount and intensity), soil type (pH, soil biological activity and organic carbon), soil type variability within a paddock, temperature and herbicide rate. Some crops are more sensitive to various herbicide groups than others. Always take a conservative approach to plant back periods, especially with sensitive or high input crops.

	Ally®A	Amicide® Advance (700g/L)B			Baton® Low (800 g/kg amine)B			Cadence®B			Eclipse® 100 SC	LV Ester 680 (680 g/L)B			Express®	Flame®	Garlon™	Goal®	Grazon™ ExtraD					Hotshot™D		Kamba® 500B			Lontrel™ Advanced 600 g/LE						Pyresta®B		Starane™ AdvancedF			Sharpen® WG	Terrain™ 500 WG	Weedmaster® Argo®
Herbicide Group	B	I	I	I	I	I	I	I	I	I	B	I	I	I	B	B	I	G	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	GI	GI	I	I	I	G	G	M
Specific details	pH 5.6–8.5H	<0.5 L/ha	0.5–0.98 L/ha	0.98–1.5 L/ha	<0.4 kg/ha	0.4–0.9 kg/ha	0.9–1.3 kg/ha	140 g/ha	200 g/ha	400 g/ha		<0.51 L/ha	0.51–1.0 L/ha	1.0–1.6 L/ha					NNSW 0.2 L/ha	NNSW 0.3 L/ha	NNSW 0.4 L/ha	NNSW 0.6 L/ha	SNSW <0.5 L/ha	NNSW <750 mL/ha	SNSW <500 mL/ha	0.20 L/ha	0.28 L/ha	0.56 L/ha	NNSW <0.0375 L/ha	NNSW 0.0375–0.15 L/ha	NNSW >0.15 L/ha	SNSW <0.15 L/ha	SNSW <0.15–0.25 L/ha	SNSW >0.25 L/ha	250–500 mL/ha	900 mL/ha	0.225 L/ha	0.45 L/ha	0.9 L/ha	9–26 g/ha	30 g/ha	
Oats	9mo	3d	3d	7d	3d	3d	7d	1d	7d	14d		3d	3d	7d	3d											1d	7d	14d	7d	7d		7d	7d	7d	3d	3d				1hr	1hr	

KEY: hr = hours, d = days, w = weeks, mo = months

A For pH 8.6 and above tolerance of crops (grown through to maturity) should be determined on a small scale, in the previous season, before sowing into larger areas.

B When applied to dry soils at least 15 mm of rain must fall prior to the commencement of the plantback period.

C Express® is broken down in soil, primarily by chemical hydrolysis, but to a lesser degree by microbial degredation. Breakdown is fastest in warm, wet acid soils and slower in cold alkaline soils. For these summer crops, if minimum soil temperatures at planting depth are less than or equal to 15°C for three consecutive days, then plantback intervals should be extended to 21 days.

D Black cracking clays. During drought conditions the plantback period may be significantly longer.

E Additional rainfall requirements need to be observed – see label.

F Do not plant susceptible crops, including cotton, pigeon peas and other pulse crops, into irrigated fields with soils containing less than 25% clay content, within 12 months of treatment with Starane™ Advanced.

G Plantback refers to rapeseed not canola.

H Soil pH determined by 1:5 soil:water suspension method.

Table 4: Residual persistence of common pre-emergent herbicides, and noted residual persistence in broad acre trials and paddock experiences [12]

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than Logran
Diuron	90 (range 1 month to 1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed long-lasting activity on grass weeds such as black/stink grass (*Eragrostis* spp.) and to a lesser extent broadleaf weeds such as fleabane

[11] 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

[12] 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

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Atrazine	60–100, up to 1 year if dry	High. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane
Simazine	60 (range 28–149)	Med./high. 1 year residual in high pH soils. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane
Terbyne® (terbulthylazine)	6.5–139	High. Has had observed long lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed long lasting activity on grass weeds such as black/stink grass (*Eragrostis* spp.)
Stomp® (pendimethalin)	40	Medium. 3–4 months residual
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months residual
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Has had observed long lasting (> 6 months) activity on broadleaf weeds such as fleabane and sow thistle
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than Trifluralin and Boxer Gold, however, weed control persists longer than Boxer Gold

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

1.7 Seedbed requirements

Oats seed needs good soil contact for germination. This can be assisted with press wheels, coil packers or rollers. Soil type determines the implement that produces the ideal seedbed.

Between 70 and 90% of seeds sown produce a plant if vigour and germination are high.

Depth of sowing, disease, crusting, moisture and other stress in the seedbed all reduce the number of plants establishing. Field establishment is unlikely to be more than 90% and may be as low as 60% if seedbed conditions are unfavourable.

Seedbed preparation is also important to emergence. A cloddy seedbed may reduce emergence, as the clods allow light to penetrate below the soil surface. The coleoptile senses the light and stops growing while still below the surface.[13]

For successful crop establishment, seed needs to be placed into soil with enough seedbed moisture for germination to occur, or into dry soil with the anticipation of rainfall to increase soil moisture levels such that germination may occur. In north-western NSW it is common for soil profiles to have high levels of plant-available water in the root-zone, coupled with a dry seedbed. This scenario may require implementation of the practice of 'moisture seeking', where seed is placed deeper in the soil than is generally recommended, with the main aim of ensuring timely crop establishment. This practice generally involves the use of tines to open a furrow to a depth of >7.5 cm, into which the seed is then placed, followed by a press wheel to close moist soil around the seed. Cox and Chapman (2007) reported that 'moisture seeking' increases cropping frequency and improves timeliness of crop establishment. Oats are ideally suited to 'moisture seeking' as they generally have a longer coleoptile length than wheat and barley.

13 District Agronomists (2008) Wheat growth and development. PROCRP 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

1.8 Soil moisture

1.8.1 Dryland

Water availability is a key limiting factor for oat production in the northern grain belt of Australia.

Devices for soil monitoring

In-situ devices that have relatively small zones of measurement and rely on good soil–sensor contact to measure soil water are at a disadvantage in shrink–swell soils where soil movement and cracking are typical. This is more important in dryland than irrigated systems as seasonal soil water levels vary from above field capacity through to wilting point or lower. Consequently, the potentially high levels of error associated with cracking and soil movement and high levels of inherent soil variability mean that increased device replication would be necessary to achieve confidence in results. This comes at an increased capital cost. Some devices (capacitance; time domain reflectometry, TDR) also have an upper measurement limit over which they are unable to accurately measure soil water. This may be a problem on high clay soils where moisture content at drained upper limit is likely to be >50% volumetric, the common limit for these devices. By comparison, the use of a portable electromagnetic induction (EMI) device to measure bulk electrical conductivity and calculate soil water has a number of advantages. The EMI is quick, allowing for greater replication, measures the soil moisture of a large volume of soil (to 150 cm depth), is not affected by cracking or soil movement, and does not require installation of an access tube, thus making it available for use on multiple paddocks. However, it is unsuitable for use in saline soils and does not apportion soil water to particular layers within the soil profile.[14]

New thoughts on soil moisture monitoring

Despite an extensive range of monitoring instruments now available, measuring paddock soil moisture is still a considerable challenge. Among the suite of instruments currently on offer, one that is increasingly being used by researchers and agronomists is the EM38 (Geonics Ltd, Ontario, Canada). This electromagnetic induction instrument is proving to have significant application potential for determining soil properties useful in precision agriculture and environmental monitoring. It is now commonly used to provide rapid and reliable information on properties such as soil salinity and soil management zones, both of which relate well to crop yield. It is also used widely in agronomic and environmental applications to monitor soil water within the root-zone. It provides an efficient means to monitor crop water use and plant-available water (PAW) in the soil profile throughout the growing season so that informed management decisions can be made (e.g. the application, timing and conservation of irrigation water and fertiliser). EM38 datasets have also proved valuable to test and validate water balance models that are used to extrapolate to other seasons, management scenarios and locations.

The EM38 is an easy-to-use, geophysical surveying instrument that provides a rapid measure of soil electrical conductivity. Soil calibrations or qualitative assessments can be used to convert this to estimates of soil water in the root-zone. This information is vital to farm management decisions based on accurate knowledge of soil PAW.[15]

Calibration of monitoring devices

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

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

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

The resulting calibration is then used to convert device output signal to gravimetric or volumetric water content. To calculate the availability of soil moisture for crop use (in mm of available water) requires further processing of the data and knowledge of a soil's PAW capacity (PAWC). A suitable characteristic may be identified from the APSoil database or SoilMapp, or electronic sensor output may be used to identify the soil's water content operating range, to make reasonable assumptions on values for drained upper limit and crop lower limit. An alternative is to use Soil Water Express (Burk and Dalgliesh 2012), a tool which uses the soil's texture, salinity and bulk density to predict PAWC and to convert electronic sensor output to meaningful soil water information (mm of available water).

Modelling of soil water

Simulation of the water balance should be considered as an alternative to field-based soil water monitoring. Considering the error surrounding in-field measurement and issues with installation of sensing devices, there is a reasonable argument that the modelling of the water balance, when initialised with accurate PAWC and daily climate information, is likely to be as accurate as direct measurement. APSIM and Yield Prophet successfully predict soil water and they should be considered for both fallow and cropping situations. CliMate is a logical choice for managing fallow water (Freebairn 2012).[16]

Effect of strategic tillage

Research shows one-time tillage with chisel or offset disc in long-term, no-tillage helped to control winter weeds, and slightly improved grain yields and profitability, while retaining many of the soil quality benefits of no-till farming systems. Tillage reduced soil moisture at most sites; however, this decrease in soil moisture did not adversely affect productivity. This could be due to good rainfall received after tillage and prior to seeding and during the crop of that year. The occurrence of rain between the tillage and sowing or immediately after sowing is necessary to replenish soil water lost from the seed-zone. This suggests the importance of timing of tillage and of considering the seasonal forecast. Future research will determine the best timing for strategic tillage in no-till systems.[17] Note that these results are from one season and research is ongoing, so any impacts are likely to vary with subsequent seasonal conditions.

See the 2015 GRDC Strategic Tillage Tips and Tactics fact sheet. http://www.grdc.com.au/Resources/Factsheets

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

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

Figure 1: Strategic tillage trials are underway at sites across the northern region. (Photo: Yash Dang)

1.8.2 Irrigation

Oats can utilise more water than any other cereal except rice (Coffman, 1961).

"Oats withstand waterlogged conditions better and generally grow well with less inputs than other winter crops".

The security of irrigated oat production and the high quality of oats produced from the irrigation areas of the Murrumbidgee and Murray valleys is attracting premiums and great interest from processors. Oat receival sites have been established in the MIA, CIA and Murray Valley in recent years and hectare contracts are being offered to encourage more production. The National Oat Breeding Program has supported the expansion of oats onto irrigation with the first National Variety Trial (NVT) irrigated oat evaluation at Yanco NSW in 2013 (Figure 2). While oat yields may not be comparable to wheat, cost inputs for fertiliser are usually less.[18]

[18] T Bray (2014) Irrigated milling oats set to roll. IREC Farmers' Newsletter – Large Area No. 190: Autumn 2014, http://irec.org.au/farmer_f/pdf_190/Milling-oat-opportunities-for-irrigators.pdf

More information

Irrigated oats gross margins, southern Queensland: https://publications.qld.gov.au/storage/f/2014-09-23T04%3A33%3A38.087Z/oats-irrigated-gm-sq.xls

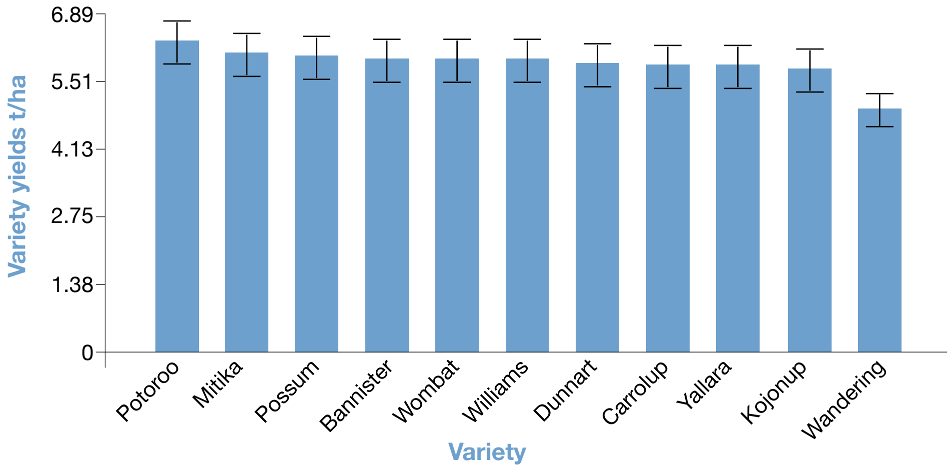


Figure 2: Yield results of an oat variety trial conducted at Yanco in 2013. (Source: NVT)

1.9 Yield and targets

1.9.1 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.[19]

Before planting, identify the target yield in grain, hay or DM required to be profitable:

- Do a simple calculation to see how much water you need to achieve this yield.
- Know how much soil water you have (treat this water like money in the bank).
- Think about how much risk your farm can take.
- Consider how this crop fits into your cropping plan, will the longer-term benefits to the system outweigh any short-term losses?
- Avoiding a failed crop saves money now and saves stored water for future crops.[20]

Mobile applications (apps) are providing tools for ground-truthing precision agriculture data. Apps and mobile devices are making it easier to collect and record data on-farm. The app market for agriculture is evolving rapidly, with new apps becoming available on a regular basis. For more information, download the GRDC Update paper, Managing data on the modern farm.[21]

More information

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

http://www.climatekelpie.com.au/understand-climate/weather-and-climate-drivers/queensland#ElNino

http://www.climatekelpie.com.au/farmers-managing-risk/climate-champion-program

CropMate

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

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

20 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

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

Australian 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, as well as El Nino Southern Oscillation status. It is designed for decision makers such as farmers whose businesses rely on the weather.

Download from the Apple iTunes store at: https://itunes.apple.com/au/app/australianclimate/id582572607?mt=8 or visit http://www.australianclimate.net.au

One of the CliMate tools*, 'Season's progress?'*, uses long-term (1949 to present) weather records to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years. It explores the readily available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons.

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

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

More information

www.australianclimate.net.au

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Seasonal-climate-outlook-improvements-changes-from-historical-to-real-time-data

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 firerisk chart as the departure from the average in units of standard deviation.[22]

The Bureau of Meteorology has recently moved from a statistics-based to a physics-based (dynamical) model for its seasonal climate outlooks. The new system has better overall skill, is reliable, allows for incremental improvements in skill over time, and provides a framework for new outlook services including multi-week/monthly outlooks and the forecasting of additional climate variables.[23]

1.9.2 Fallow moisture

For a growing crop there are two sources of water: first, the water stored in the soil during the fallow, and second, the water that falls as rain while the crop is growing. As a farmer, you have some control over the stored soil water; you can measure how much you have before planting the crop. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when you need it.[24]

HowWet?

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

22 Australian CliMate—Climate tools for decision makers, www.australianclimate.net.au

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

24 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

in the soil is calculated based on surface soil moisture, temperature and soil organic carbon.

HowWet?:

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

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

Many grain growers are in regions where stored soil water and nitrate at planting are important in crop management decisions. This is of particular importance to northern Australian grain growers with clay soils where stored soil water at planting can constitute a large part of a crop's water supply.

Questions this tool answers

- How much longer should I fallow? If the soil is near full, maybe the fallow can be shortened.
- Given my soil type and local rainfall to date, what is the relative soil moisture and nitrate-N accumulation over the fallow period compared with most years? Relative changes are more reliable than absolute values.
- Based on estimates of soil water and nitrate-N accumulation over the fallow, what adjustments are needed to the N supply?[25]

Inputs

- a selected soil type and weather station
- an estimate of soil cover and starting soil moisture
- rainfall data input by the user for the stand-alone version of HowOften?

Outputs

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

Reliability

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

Soil descriptions are based on generic soil types with standard organic carbon (C) and C/N ratios, and as such should be regarded as indicative only and best used as a measure of relative water accumulation and nitrate mineralisation.[26]

1.9.3 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.

Water-use efficiency relies on:

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

25 Australian CliMate—How Wet/N, http://www.australianclimate.net.au/About/HowWetN

26 Australian CliMate—How Wet/N, http://www.australianclimate.net.au/About/HowWetN

GRDC Grains Research & Development Corporation

- the crop's ability to convert biomass into grain (harvest index).

Water is the principal limiting factor in rain-fed cropping systems in northern Australia. The objective of rain-fed cropping systems is to maximise the proportion of rainfall that crops use, and minimise water lost through runoff, drainage and evaporation from the soil surface and to weeds.

Rainfall is more summer-dominant in the north of the northern region, and as such both summer and winter crops are grown. However, rainfall is highly variable and can range, during each cropping season, from little or no rain to major rain events that result in waterlogging or flooding. The southern part of the northern region is dominated by a winter rainfall pattern.

Storing water in fallows between crops can be an effective tool to manage the risk of rainfall variability, Fortunately, many cropping soils in the northern region have the capacity to store large amounts of water during the fallow.[27]

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

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

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

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

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

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

Ways to increase yield

In environments such as western NSW where yield is limited by water availability, there are four ways of increasing yield (Passioura and Angus 2010):

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

The last three of these all improve WUE.[28]

Knowledge of evaporation for the northern growing region soils is limited yet it is the largest part of the water balance. Since 2010 Queensland Department of Natural Resources and Mines (DNRM) researchers have been measuring evaporation directly for a range of soils using lysimetry techniques. They found most, but not all, soils evaporate at a similar rate. There are significant interactions between soil water, climate and rainfall

27 GRDC (2009) Water use efficiency—converting rainfall to grain. GRDC Fact Sheet Northern Region, http://www.grdc.com.au/~/media/607AD22DC6934BE79DEAA05DFBE00999.pdf

28 GRDC (2009) Water use efficiency—converting rainfall to grain. GRDC Fact Sheet Northern Region, http://www.grdc.com.au/~/media/607AD22DC6934BE79DEAA05DFBE00999.pdf

that influence this rate of evaporation. This data has been used to test current modelling assumptions, better parameterise models, and is now directly contributing to improving predictions of the soil water balance component of models such as APSIM, APSIM-SWIM, HowLeaky, and HowWet (via CLiMate), by providing more realistic responses for our soils and climates.

For more information, visit http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/How-much-water-is-lost-from-northern-crop-systems-by-soil-evaporation [29]

The French–Schultz approach

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

In this model, potential crop yield is estimated as:

Potential yield (kg/ha) = WUE (kg/ha.mm) x [crop water supply (mm) – estimate of soil evaporation (mm)]

where crop water supply is an estimate of water available to the crop, i.e. soil water at planting plus in-crop rainfall minus soil water remaining at harvest.

In the highly variable rainfall environment in the northern region, it is difficult to estimate in-crop rainfall, soil evaporation and soil water remaining at harvest. However, this model may still provide a guide to crop yield potential.

The French–Schultz model has been useful in giving growers performance benchmarks where yields fall well below these benchmarks, it may indicate something wrong with the crop's agronomy or a major limitation in the environment. There could be hidden problems in the soil such as root diseases, or soil constraints affecting yields. Alternatively, apparent underperformance could be simply due to seasonal rainfall distribution patterns, which are beyond the grower's control.[30]

Challenging the French-Schultz model

Application of the French-Schultz model for the northern region has been challenged in recent times.

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

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

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

Researchers have analysed some of the consequences of the shift from winter to summer rainfall between southern and northern regions in terms of implications for management and breeding. They advise caution on the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single-crop and whole farming systems level (i.e. $/ha.mm).

29 GRDC (2014), How much water is lost from northern crop systems by soil evaporation. http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/How-much-water-is-lost-from-northern-crop-systems-by-soil-evaporation

30 GRDC (2009) Water use efficiency—converting rainfall to grain. GRDC Fact Sheet Northern Region, http://www.grdc.com.au/~/media/607AD22DC6934BE79DEAA05DFBE00999.pdf

1.9.4 Nitrogen use efficiency

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

In cracking clay soils of the northern grains region, saturated soil conditions between fertiliser application and crop growth can lead to significant losses of N from the soil through denitrification. The gases lost in this case are nitric oxide, nitrous oxide and di-nitrogen (N_2). Isotope studies in the northern region have found these losses can be >30% of the N applied. Direct measurements of nitrous oxide highlight the rapidity of loss in this process.

Insufficient rainfall after surface application of N fertilisers can result in losses from the soil through volatilisation. The gas lost in this case is ammonia. Direct measurements of ammonia losses have found that they were generally <15% of the N applied, even less in in-crop situations. An exception occurred with the application of ammonium sulfate to soils with free lime at the surface, where losses were >25% of the N applied. Recovery of N applied in-crop requires sufficient in-crop rainfall for plant uptake from otherwise dry surface soil.[31]

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

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

1.10 Disease status of paddock

1.10.1 Soil testing for disease

Stubble testing

Oat crops are considered "symptomless hosts" of crown rot that may contribute to the maintenance of inoculum.of the disease. Crown Analytical Services (Moree, NSW) provides commercial testing for crown rot. Some of the current strategies for management of crown rot are to control grass hosts prior to cropping, rotate susceptible cereals with non-host break crops, inter-row sowing, and grow tolerant varieties. It is therefore very important for crown rot testing to be carried out on a paddock, so that growers and consultants can determine whether crown rot is present and if so, its severity. An informed decision can then be made regarding crop choice and farming system.

Testing involves a visual assessment on stubble followed by a precise plating test. This is the only way to accurately test for the disease. Results are provided to the grower and consultant within ~4 weeks of receiving the sample.

Crown Analytical Services provides sample bags and postage-paid packs.[32]

Check your cereal crops for crown rot between grain-fill and harvest. Collect plant samples from deep within the paddock by walking in a large 'W' pattern, collecting five plants at 10 different locations. Examine each plant for basal browning, record the percentage of plants showing the symptom and then put in place appropriate measures for next year. To see the honey/dark brown colour more easily, the leaf sheaths should be pulled back. This symptom may not appear on all stems of an infected plant and is difficult to see in oats.

As a general rule, the risk for a cereal in the next season will be:

- low, if <10% of plants infected

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

32 Crown Analytical Services, https://sites.google.com/site/crownanalyticalservices/

- medium, if 10–25% of plants infected
- high, if >25%t of plants are infected[33]

Soil testing

PreDicta B (B = broadacre) is a DNA-based soil testing service to identify which soil-borne pathogens pose a significant risk to broadacre crops prior to seeding.

It has been developed for cropping regions in Australia and includes tests for:

- cereal cyst nematode (CCN)
- take-all (Gaeumannomyces graminis var. tritici (Ggt) and G. graminis var. avenae (Gga))
- rhizoctonia barepatch (Rhizoctonia solani AG8)
- crown rot (Fusarium pseudograminearum)
- root lesion nematode (Pratylenchus neglectus and P. thornei)
- stem nematode (Ditylenchus dipsaci)

More information

http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

PreDicta B samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program.

PreDicta B is not intended for in-crop diagnosis. That is best achieved by sending samples of affected plants to your local plant pathology laboratory.

Note that oats is not very susceptible to crown rot, but does host it.

Agronomist's view

1.11 Insect status of paddock

1.11.1 Insect sampling of soil

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

Soil insects include:

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

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

- Weedy fallows and volunteer crops encourage soil insect build-up.
- Insect numbers decline during a clean long fallow due to lack of food.
- Summer cereals followed by volunteer winter crops promote the build-up of earwigs and crickets.
- High levels of stubble on the soil surface can promote some soil insects due to a food source, but this can also mean that pests continue feeding on the stubble instead of germinating crops.
- No-tillage encourages beneficial predatory insects and earthworms.

33 www.grdc.com.au/uploads/documents/GRDC_CrownRot_North.pdf

- Incorporating stubble promotes black field earwig populations.
- False wireworms are found under all intensities of cultivation but numbers decline if stubble levels are very low.

Soil insect control measures are normally applied at sowing. Since different insects require different control measures, the species of soil insects must be identified before planting.

Soil sampling by spade

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

Germinating-seed bait technique

Immediately following planting rain:

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

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

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

Detecting soil-dwelling insects

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.

For current chemical control options see the websites of Pest Genie Australia or APVMA.[34]

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

SECTION 2

Pre-planting

FAQ 2.1 Varietal performance and ratings yield

The choice to grow oats compared to other crops is indeed as important as the selection of an appropriate variety. Oats are often thought of as an "easy" crop to grow but attention to detail is required to produce high yields and quality. Weed control options remain limited compared to other cereal crops and timely grain harvest is important as most varieties shed their grain easily.[1]

When selecting a variety there are a number of considerations:

What is the crop being used for?

- grazing only
- dual-purpose grazing and grain
- hay (export or domestic)
- silage
- grain (milling or stock feed)

Once an end use has been determined, a suitable variety can be selected. This variety needs to match the following criteria for an individual's farm.

- High/low rainfall zone (Figure 1)
- Pests/diseases present in the paddock
- Moisture status of the paddock
- Nematode status
- Proximity to previous year's oat paddock
- If the crop is to be sown into last year's oat stubble or not
- Soil type (e.g. acid soils)
- Sowing date
- Proximity of markets if a specialty grain is to be grown
- When is feed most important – in early or late winter? [2],[3]

1 Agriculture Victoria (2015) Growing oat. DEDJTR Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-oat

2 P. Heuston (2016) Personal comms

3 NSW DPI (2015) Winter crop variety growing guide 2015. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

Figure 1. Regional map of NSW. (Source: NSW DPI)

2.1.1 Yielding ability

For oats the yielding ability of the crop will depend on the purpose the crop is being grown for: if it is for hay and silage it will determined in not only tonnes per hectare but quality of the hay and standability of that crop late in the season.

If solely for grazing it might be measured in early growth and dry matter (DM) production or even weight gain by stock who have grazed the paddock.

Dual-purpose would focus not only on dry matter (DM) production and weight gain, but also in the grain recovery of the crop after grazing.

If for grain, yield may be the only unit of measure but if that grain is destined for the milling markets, quality may be king. [4]

Tables 1-4 reflect this in that there are separate tables for grain only oats as opposed to dual-purpose crops.

4 P. Heuston (2016) Personal comms

Table 1: Higher Tablelands dual-purpose compared with Eurabbie = 100%

Consider Nile, Bass and Blackbutt for very early sowing. Eurabbie is outstanding for grain recovery after grazing. Mannus is outstanding for grain quality.

Variety	1st Grazing DM Eurabbie = 2.37 t/ha	2nd Grazing DM Eurabbie = 2.51 t/ha	Grain Recovery Eurabbie = 2.94 t/ha	Ungrazed Eurabbie = 4.57 t/ha
Bass	94	95	85	92
Bimbil	88	93	87	84
Blackbutt	89	91	84	89
Eurabbie	100	100	100	100
Mannus	87	91	87	72
Nile	99	97	85	93

Table 2: Tablelands/Slopes dual-purpose compared with Bimbil = 100%

Consider Eurabbie or Blackbutt for the Tablelands, or areas with later maturity. Eurabbie is outstanding for grain recovery after grazing. Preferred varieties for feeding grain to livestock are Mannus, Yiddah and Yarran.
Outclassed.

Variety	1st Grazing DM Bimbil = 2.90 t/ha	2nd Grazing DM Bimbil = 2.34 t/ha	Grain Recovery Bimbil = 2.07 t/ha	Ungrazed Bimbil = 2.50 t/ha
Bimbil	100	100	100	100
Blackbutt	102	97	86	86
Cooba #	106	106	87	87
Eurabbie	114	107	119	118
Mannus	99	97	98	101
Yarran #	103	95	105	105
Yiddah	109	111	86	85

Table 3: Slopes/Plains dual-purpose compared with Bimbil = 100%

For the Slopes, consider Eurabbie, Mannus, Bimbil and Yiddah for grazing and especially Eurabbie and Mannus for grain recovery. For the Plains consider Yarran, Yiddah and Coolabah for grazing and especially Yiddah for grain recovery. Preferred varieties for feeding grain to livestock are Mannus, Yiddah and Yarran. # Outclassed.

Variety	1st Grazing DM Bimbil = 2.09 t/ha	2nd Grazing Bimbil = 2.34 t/ha	Grain Recovery Bimbil = 2.26 t/ha	Ungrazed Bimbil = 2.59 t/ha
Bimbil	100	100	100	100
Cooba #	106	106	97	86
Eurabbie	107	107	112	120
Mannus	99	97	101	94
Yarran #	106	95	120	103
Yiddah	111	111	103	87

Table 4: Grain only varieties compared with Mitika (2010–2014) – the more trials, the greater the reliability.

Yield results are a combined across sites analysis of the NVT yield trials from 2010–2014. Preferred milling varieties are Mitika and Yallara. Preferred variety for feeding grain to livestock is Mitika. # Outclassed.

	North-east		South-east		South-west	
Variety	Mitika = 3.28 t/ha	No. of trials	Mitika = 4.10 t/ha	No. of trials	Mitika = 3.22 t/ha	No. of trials
Bannister	113	4	105	17	106	10
Mitika	100	4	100	17	100	12
Mortlock #	–	–	90	3	–	–
Possum	104	4	98	17	100	12
Williams	115	4	105	17	101	10
Wombat	108	4	98	17	98	12
Yallara	108	4	94	17	94	12

The trial work conducted by GRDC National Variety Trials or NVT are a reflection of the most recent year's crop yields and a long term average for a number of districts. This trial work covers numerous crops including oats.

The NVT program was established in 2005 by the GRDC and is managed by the Australian Crop Accreditation System Limited (ACAS). It is a national program of comparative crop variety testing with standardised trial management, data generation, collection and dissemination. This is managed through an internet accessed database that ensures a common approach and uniformity across the system.[5]

To go to the website click on the link: http://www.nvtonline.com.au/

2.1.2 Varietal characteristics

Variety selection depends on the crop use, sowing date, likely diseases, and tolerance to acid soil, grain quality and possible market outlet. Most varieties are suitable for grazing.

Growers are warned that there are now no commercial varieties with resistance to all the current field pathotypes of stem rust. Growers should also be aware that there are a number of leaf (crown) rust pathotypes present in NSW, with pathotypes present in central and northern NSW that have overcome many of the resistance genes in oat varieties bred for southern Australia.

Milling varieties

Milling oats are dehulled, steamed and flaked or milled before processing. The healthy oats are made into oatmeal and breakfast foods, health bars, bakery goods and baby foods. Interest by consumers in oat noodles, oat milk, oat rice and oat health care products is also growing.[6]

Bannister⁽ᴰ⁾: Released in Western Australia in 2012 as a milling oat variety for the western region. It has high grain yield potential and has performed well in trials in southern NSW. It is taller than Mitika and heads about 3 to 4 days later than Mitika. It is susceptible to and intolerant of cereal cyst nematodes. Bannister is resistant to leaf rust and moderately resistant to bacterial blight. Bannister has slightly lower hectolitre weight and slightly higher screenings compared to Mitika. Seednet.

Mitika⁽ᴰ⁾: Mitika is a dwarf milling oat released in 2005. It is earlier maturing than Possum and Echidna and this trait favours Mitika in a dry finish. Mitika was resistant to stem rust until 2010 when a new pathotype of stem rust was identified, rendering it susceptible moderately susceptible to leaf rust. Mitika has improved resistance to bacterial blight and is superior to Echidna for septoria resistance. Mitika is susceptible to BYDV, septoria and red leather leaf disease. It is very susceptible and intolerant of cereal cyst nematode and moderately intolerant of stem nematode and is not recommended in areas where either of these nematodes are a problem. Mitika has high hectolitre weight, low screenings and high groat percent compared to Echidna. Mitika also has improved feed quality with low husk lignin and high grain digestibility. Heritage Seeds.

Mortlock: Medium height, strong strawed grain oat. Can be leniently grazed. It has a consistently high test weight, protein content and lower screening losses with light coloured grain, but discolours easily. Low yielding compared to Mitika and Possum. Released by Agriculture Western Australia in 1983.

Possum⁽ᴰ⁾: Possum is a dwarf milling grain variety. It is a replacement for Echidna in medium and high rainfall areas. Possum has a similar yield to Echidna in high rainfall zones and slightly lower yield in medium rainfall zones. Possum also has a high husk lignin content like Echidna. It has better milling quality than Echidna and has similar hectolitre weight and fewer screenings than Euro. It is an improvement compared to Echidna for stem rust, leaf rust and Septoria resistance. Like Echidna, Possum is

5 National Variety Trials About national variety trials

6 AEGIC. Australian grain note: Oats. Australian Export Grains Innovation Centre, http://www.aegic.org.au/media/23324/140214%20Oats%20Note.pdf

susceptible to bacterial blight and barley yellow dwarf virus (BYDV) and very susceptible and intolerant to cereal cyst nematode. Possum is not recommended for areas where cereal cyst or stem nematode is a problem. Possum is susceptible to red leather leaf and intolerant of stem nematode. Developed by SARDI, released in 2003. Seednet.

Williams⦶: Released in Western Australia in 2013, Williams has a high grain yield potential and has performed well in trials throughout NSW. Williams is an early to mid season variety similar to Yallara, but three to seven days later than Mitika. Taller than Mitika by 15 cm, 5 cm taller than Bannister, and 15 cm shorter than Yallara. Williams is resistant to leaf rust and depending on the stem rust pathotype present can range from moderately resistant to susceptible. It is susceptible and intolerant to cereal cyst nematodes. Williams is resistant to bacterial blight and moderately resistant to moderately susceptible to BYDV. Williams has lower hectolitre weight and higher screenings compared to Mitika. Williams is not recommended for low rainfall areas due to higher screenings. Heritage Seeds.

Wombat⦶: A dwarf milling variety, which is similar in height to Possum and slightly taller than Mitika. It is a mid season variety flowering about six days later than Mitika. Wombat was the first dwarf milling variety with cereal cyst nematode resistance and tolerance. It is also moderately tolerant to stem nematode. Wombat has high hectolitre weight and low screenings compared to the feed variety Potoroo, which was the first dwarf variety with cereal cyst nematode resistance and tolerance. It also has a high groat percent, slightly higher than Mitika. Developed by SARDI. Seednet.

Yallara⦶: A medium–tall, early to mid season variety similar to Euro for flowering and maturity. Yallara was released in 2009. Yallara is a Euro look-alike milling line with slightly better grain quality, but not as susceptible to stem rust. It is resistant but intolerant to cereal cyst nematode. It is moderately susceptible to BYDV and septoria. Yallara is susceptible and intolerant to stem nematode and moderately susceptible to red leather leaf disease. Yallara has excellent grain quality. It has a high hectolitre weight, low screenings and a high groat percent. Yallara has bright, plump grain suitable for the milling industry and specialised feed end-uses like the horse racing industry as well as human consumption. Yallara was evaluated for hay production and although the hay yield is lower than popular hay varieties it has excellent hay quality. Seednet.

Feed grain, hay and grazing varieties

Intermediate and late-maturing varieties remain vegetative until late in the season and provide a longer duration of grazing for livestock.[7]

Aladdin⦶: New late maturity grazing variety with good semi-erect early growth and quick recovery from grazing. In late 2014, another pathotype of crown rust was found that can infect Aladdin, so its previous status as resistant to rust has been revoked. Selected for Queensland and northern NSW. Released by DAFF Qld and Heritage Seeds in 2012, and available through Heritage Seeds.

Bimbil: Dual-purpose type suitable for early to mid season sowing, grazing and grain recovery. Early and total dry matter production are similar to Cooba. Grain yield and grain recovery after grazing are better than Cooba. Straw is shorter and stronger than Cooba but it may still lodge. High groat percentage. Bred by NSW DPI at Temora. Released in 1993.

Blackbutt: Popular on the higher tablelands and tablelands/slopes, especially for early sowing. Late maturing provides extended grazing with excellent grain recovery. Straw is strong and of medium height. Good resistance to frost damage after grazing. Tends to have small grain and a low test weight. Bred by NSW DPI at Glen Innes. Released in 1975.

Brusher⦶: A tall, early-mid season hay variety with improved hay digestibility. Resistant and moderately intolerant to cereal cyst nematode. Intolerant of stem nematode. Low husk lignin. Released by SARDI in 2003. AEXCO.

7 DAF Qld (2015) Forage oat variety guide 2015. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

Comet⍉: New medium-late maturity grazing variety released by Pacific Seeds, semi-erect early growth, with early growth similar to Aladdin. High level of resistance to leaf rust. Available through Pacific Seeds.

Cooba⍉: Suitable for early sowing, extended grazing and good grain recovery in most areas. Early growth is slow. It is mid season maturing. Medium straw height and strength, average grain size, low husk percentage, high test weight and high groat percentage. Bred by NSW DPI at Glen Innes, selected at Temora. Released in 1961.

Cooee⍉: Forage oat that has good early growth and dry matter production for multiple grazings. Erect habit with good regrowth, with fine stems. Late maturing. Released by Wrightson Seeds in 2010.

Coolabah⍉: Suitable for lenient grazing and good recovery for grain in most areas. Quick early growth. Early maturing. Straw of medium height and strength. Fairly long grain, satisfactory test weight, high husk percentage. Bred by NSW DPI at Temora. Released in 1967.

Drover⍉: Intermediate growth habit. Now susceptible to leaf rust due to a new race that appeared in southern Qld in 2013 (in the absence of this race it will appear resistant). Suitable for grazing and hay. Released by Pacific Seeds in 2006.

Eurabbie: Winter habit. Semi-dwarf with similar maturity to Blackbutt and later than Cooba by about 10 days. Can be very short after heavy late grazing, possibly resulting in harvesting difficulties. Grazing management is crucial for high grain recovery yields at sufficient height. Excellent grain recovery yields, despite its susceptibility to BYDV. Grain quality is generally inferior and very similar to Blackbutt in tablelands/slopes situations. Generally lower quality than Cooba from slopes/plains samples. Bred by NSW DPI at Temora. Released in 1998.

Forester⍉: Very late hay variety adapted to high rainfall and irrigated cropping regions. It is three days later than Riel and three weeks later than Wintaroo. Forester has excellent early vigour, lodging and shattering resistance. Good foliar disease resistance spectrum. It is moderately susceptible to cereal cyst nematode. Good hay colour, but like all late hay varieties may not resist hot dry winds as well as earlier varieties. Forester has excellent hay quality. Released by SARDI in 2012. Seed of Forester is available from AGF Seeds, Smeaton, Victoria.

Galileo⍉: Forage oat that has good emergence, vigour and early growth. Good dry matter production for early grazing. Late maturing, similar to Enterprise. Moderately tolerant to BYDV. Moderately resistant to crown rust. Released by Heritage Seeds in 2006.

Genie: A Late maturity erect grazing variety with quick early growth and very high dry matter yields. Susceptible to leaf and stem rust in the northern region. Selected for Queensland and northern NSW. Released by DAFF Qld and Heritage Seeds in 2008 and available through Heritage Seeds.

Graza 51⍉: Erect, quick growing, medium to late grazing variety developed by Agriculture Canada. Susceptible to leaf and stem rust in the northern region. Released by Pioneer Hi-Bred in 2007. Seed available through Elders.

Graza 80⍉: Erect, quick growing, late maturing grazing variety developed by Agriculture Canada. Susceptible to leaf and stem rust in the northern region. Released by Pioneer Hi-Bred in 2005. Seed available through Elders.

Graza 85⍉: New grazing forage oat released by Elders. Medium to medium-quick maturity, with good early vigour, quicker to first grazing than Graza 80. A high tillering oat with soft, broad leaves, with a low growing point. Improved tolerance to rust over both Graza 80 and Graza 51. Very limited information available on its performance in NSW. Seed available through Elders.

Kangaroo⍉: Tall, mid–late season hay variety. Cereal cyst nematode resistant and moderately tolerant. High husk lignin. Released by SARDI in 2005. AEXCO.

Mannus⁽ᴾ⁾: Tall, strong strawed, mid maturing variety for feed grain. Grain yield after grazing is similar to Eurabbie on the tablelands/slopes but lower on the slopes/plains. Physical grain quality is better than Eurabbie. Large uniform grain size with high test weight, high groat percentage, medium protein and fat content. Low lignin husk. Moderately susceptible to BYDV, better than Eurabbie and Yarran. May exhibit physiological yellowing in winter. Bred by NSW DPI at Temora. Released in 2006. Waratah Seeds.

Moola⁽ᴾ⁾: Grazing variety with rapid early growth developed by Agriculture Canada and released in 1998 by DAFF Qld. Susceptible to leaf and stem rust in the northern region.

Mulgara⁽ᴾ⁾: Tall mid season hay oat similar in heading time and height to Wintaroo with cereal cyst nematode and stem nematode resistance and tolerance. Mulgara is an improvement compared to Wintaroo for resistance to stem rust and bacterial blight, lodging and shattering resistance and early vigour. Hay yield is an improvement compared to Brusher but slightly lower than Wintaroo. Hay quality is similar to Wintaroo. Mulgara has excellent hay colour and resists brown leaf at hay cutting. Grain yield and quality is similar to Wintaroo with lower screenings, higher protein and groat percent. Mulgara has high husk lignin. Released by SARDI in 2009. AEXCO.

Nile: A medium height, late maturing variety, producing good winter grazing in tableland districts. Grain recovery yields depend heavily on good late-spring finishing conditions. It has good BYDV tolerance. Released by Tasmanian Department of Agriculture in 1982.

Outback: A forage oat that has quick early growth and dry matter production. Susceptible to leaf rust. Erect habit and mid to late maturity. Released in 2005, marketed by Seed Distributors.

Quoll⁽ᴾ⁾: High yielding semi-dwarf grain oat. Resistant to crown rust and some resistance to stem rust. Released by SARDI in 1999. Heritage Seeds.

Saia: Grazing only type. Has a much smaller seed than most other varieties, so use lower seeding rates. Produces early feed and extended grazing. Recovery from grazing is sometimes poor. Tall, fine, weak straw. Highly tolerant to aluminium and manganese toxicity. Its blackish grain can be regarded as a contaminant if mixed with white grained varieties. Introduced from Brazil and has been used as a green manure crop in some areas.

Yarran: A medium height, early–mid season maturing variety for feed grain. Performs better than Coolabah for grain recovery, or grain-only on the slopes/plains, but is slightly inferior to Coolabah for grazing production. In very dry years it outyields Echidna in grain-only trials. Large grain with a high test weight, protein percentage and medium to low husk content. Very susceptible to BYDV. Bred by NSW DPI at Temora. Released in 1988.

Yiddah⁽ᴾ⁾: A tall, strong strawed, early maturing variety for feed grain. It can be sown earlier than Yarran and has quicker early feed production. Grain yield after grazing is similar to Yarran. Physical grain quality is better than Yarran. Very large grain with high test weight and protein percentage and low husk content. Low lignin husk. Moderate tolerance to BYDV, effective stem and some crown rust resistance. Bred by NSW DPI at Temora. Released in 2001. Waratah Seeds.

Oat varieties that are no longer in commercial seed production by the respective marketing or seed company but may still be available on a limited basis.

Barcoo: Semi-prostrate grazing variety with medium maturity, suitable for early-mid season sowing, grazing and grain recovery. Released by Pacific Seeds in 1996.

Bass⁽ᴾ⁾: Suitable for early sowings on the higher tablelands. Provides extended grazing with good grain recovery. Strong straw. Good BYDV tolerance. Released by the Tasmanian Institute of Agricultural Research and the Department of Primary Industries, Water and the Environment in 1998. Culgoa II. A semi-prostrate variety mainly for grazing. Slow initial growth. Released by DAFF Qld in 1991.

Dawson⁽ᵖ⁾: Medium-late maturity grazing variety with erect early growth and high dry matter yields. Susceptible to leaf rust. Ideally suited to cattle, particularly in a continuous grazing situation. Released by Pacific Seeds in 2008.

Enterprise: Erect grazing forage oat. Provides good early grazing. Poor recovery after hard grazing and/ or frosting. After grazing, grain maturity is much later than Blackbutt. Released by Heritage Seeds in 1993.

Graza 50: Erect, quick growing grazing variety developed by Agriculture Canada. Released by Pioneer Hi-Bred in 1994. Austgrains International.

Graza 68: Semi-erect, medium growing grazing variety developed by Agriculture Canada. Released by Pioneer Hi-Bred in 1998. Austgrains International.

Gwydir: Semi-prostrate grazing variety developed jointly by University of Queensland/ DAFF Qld/ Pacific Seeds. Released by Pacific Seeds in 1999.

Lordship: Long season, late maturing variety. Maturity similar to Enterprise and Graza 50. Excellent early vigour and forage production. Will grow tall if ungrazed but is moderately resistant to lodging. Good BYDV resistance. Released by Heritage Seeds in 2000.

Nugene⁽ᵖ⁾: A semi-erect grazing oat with quick early growth. Late maturing after grazing. Susceptible to leaf and stem rust in the northern region. Released by DAFF Qld and Heritage Seeds in 2000. Heritage Seeds.

Quamby: Very erect, similar to Enterprise. Very late maturing. If grazed when tall, does not recover well. Released by Tasmanian Department of Agriculture in 1988.

Volta⁽ᵖ⁾: A semi-erect grazing variety. Medium–late maturity. Susceptible to leaf and stem rust in the northern region. Selected for Queensland and northern NSW. Released by DAFF Qld and Heritage Seeds in 2003 and available through Heritage Seeds.

Warrego: A semi-prostrate grazing oat with quick early growth. Developed by North Dakota State University and released by Pacific Seeds in 1999.

FAQ

Feeding value of oats grain

The GRDC-supported Premium Grains for Livestock Program project demonstrated large differences between varieties in whole grain digestibility. Cattle feeding trials have subsequently demonstrated these differences translate into large differences in grain digestibility. Most of the difference in whole grain digestibility is caused by varietal differences in the lignin content of the oat husk. Where varieties have a high husk lignin content, digestion of both the husk and the underlying grain is poor. Husk lignin content is assessed using a simple staining test (phloroglucinol stain test). A list of lignin ratings of a range of oat varieties is presented in the following table. While other seasonal factors affect whole grain digestibility, varieties with a high husk lignin rating will inherently have low whole grain digestibility. NIR tests have been developed to measure the feeding value of grains. [8]

[8] NSW DPI (2015) Winter crop variety growing guide 2015. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

Table 5: Grain quality comparisons

Variety	Hectolitre Weight (kg/hl)	Screenings <2mm	1000 Grain weight (g)	Kernel (%)	Probability of reaching milling grade	Protein (%)	Oil (fat) (%)	Hull lignin content
Semi-dwarf (husked)								
Bannister	MH	ML	MH	MH	H	M	M	H
Echidna	M	MH	M	ML	L	M	M	MH
Mitika	H	L	H	MH	H	MH	M	L
Possum	MH	L	MH	MH	H	MH	M	H
Potoroo	L	MH	M	ML	-	M	MH	H
Wombat	H	M	MH	H	H	MH	M	H
Semi-dwarf (naked)								
Numbat	VH	H	L	-	-	H	VH	-
Tall (husked)								
Brusher	M	M	MH	M	-	MH	M	L
Forester	L	M	L	L	-	M	M	H
Glider	L	M	M	ML	-	MH	ML	L
Kangaroo	M	ML	MH	ML	-	M	M	H
Mulgara	M	M	MH	MH	-	MH	M	H
Tammar	L	H	L	ML	-	MH	M	SEG
Tungoo	L	H	L	ML	-	MH	M	L
Wallaroo	M	M	M	MH	-	M	MH	L
Williams	MH	M	M	M	MH	M	M	MH
Wintaroo	M	M	MH	MH	-	M	M	L
Yallara	H	L	H	H	VH	MH	L	H

Value for trait: L = low, ML = moderately low, M = medium, MH = moderately high, H = high, VH = very high, - not applicable

Research conducted at Wagga Wagga Agricultural Institute in 2003, as part of the GRDC-supported Premium Grains for Livestock Program, shows great variations in the digestibility and suitability of common oat varieties as cost-effective feed grains.

The research revealed more than a 20% variation in digestibility among eight oats tested in a cattle production trial.

Both variety and environment (growing conditions) influence digestibility. The varietal effect is correlated with lignin (an indigestible carbohydrate) levels in the hulls of the grain — high lignin content results in low digestibility.

Dual-purpose oat varieties like Cooba have high digestibility and varieties grown strictly for milling score poorly.[9]

9 R Nicoll (2003) Oats are oats are oats? Not at all. Ground Cover Issue 43, GRDC, http://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-43-SA/Oats-are-oats-are-oats-not-at-all-by-Roger-Nicoll#sthash.7DBgVSI2.dpuf

Table 6: Varieties/lignin

Low lignin (1)	Medium lignin (2-3)	High lignin (4-5)
Bass	Blackbutt	Carrolup
Bimbil	Quoll*	Coolabah
Cooba		Echidna
Eurabbie		Euro
Nile		Hotham
Yarran		Mortlock
Yiddah		PO 548
		Pallinup
		Condomine
		Bettong

The South Australian Research and Development Institute (SARDI) leads the National Oat Breeding program, developing improved milling oats – including improved nutritional value.

One of the program's most successful varieties, Mitika, now comprises more than 80% of the oats used by Uncle Tobys Australia in popular porridge and muesli bar snacks.

Mitika has high grain yield potential, improved disease resistance – as well as increased levels of β-glucan (beta-glucan) compared to other oat varieties.

2.1.3 Maturity

The maturity, or length of time taken for a variety to reach flowering, depends on vernalisation, photoperiod and thermal time requirements. Recommended sowing times are arrived at by assessing the maturity of varieties in different environments and with different sowing times.

Table 7: Sowing times for oats in regions of New South Wales

Variety	January		February				March				April				May				June		
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
Higher Tablelands/Tablelands: Dual-purpose – grazing and/or grain recovery																					
Bass, Blackbutt, Nile	>	★	★	★	★	★	★	★	★	★	<	<									
Eurabbie			>	>	★	★	★	★	★	★	★	★	★	★	<	<					
Bimbil, Mannus					>	>	★	★	★	★	★	★	★	★	<	<					
Tablelands/Slopes: Dual-purpose – grazing and/or grain recovery																					
Blackbutt					>	★	★	★	★	<	<	<	<								
Eurabbie					>	★	★	★	★	★	★	<	<								
Cooba#						>	★	★	★	★	<	<	<	<	<						
Bimbil, Mannus, Yiddah								>	★	★	★	★	<	<	<						
Coolabah#, Yarran#									>	★	★	★	★	<	<						
Slopes/Plains: Dual-purpose – grazing and/or grain recovery																					
Cooba#, Eurabbie						>	★	★	★	★	★	<	<	<	<						
Bimbil, Mannus, Yiddah								>	★	★	★	★	★	★	<	<	<				
Coolabah#, Yarran#									>	★	★	★	★	★	<	<	<				
Tablelands/Slopes grain only																					
Bannister, Mitika, Mortlock#, Possum, Williams, Wombat, Yarran #															>	★	★	★	<	<	<

Variety	January		February				March				April				May				June		
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
Slopes/Plains grain only																					
Bannister, Mitika, Possum, Williams, Wombat, Yallara															>	★	★	★	★	<	<
Mortlock#, Yarran#															>	★	★	★	★	★	<

> Earlier than ideal, but acceptable.
★ Optimum sowing time.
< Later than ideal, but acceptable.
Outclassed varieties

Warning: High soil temperatures (> 25°C) with early sowings may reduce germination and establishment.

2.1.4 Grain

While not often used as a grain in feedlot rations, the performance of cattle that are fed oats is equivalent to performance when cattle are fed other more commonly used grains. Oats have a slightly lower energy range than most other grains. They have a high fibre content, and are considered a safer grain to feed than either wheat or barley. When trialled experimentally, oats-fed cattle consumed similar amounts of grain to barley-fed cattle.

The trial showed that when daily feed intake is similar between animals fed either barley or oats, there is a strong similarity between their average daily gains (ADG) and their feed conversion ratios (FCR).[10]

Table 8: Properties of various grains

Foodstuff	Dry matter (DM) (%)	Starch (%)	Metabolisable energy (ME) (MJ/kg DM)		Crude protein (CP) (% DM)	
			Average	Tested range	Average	Tested range
Oats	90	50	10.5	8.5–12.5	10.5	8–12
Barley	90	59–61	13	12.5–13	11	10–12
Wheat	90	60–76	13	12.5–13.5	12	11–13
Sorghum	90	75	13	12.5–13	9	5–11
Maize	90	76	13.5	13–14	9.5	9.0–10

Feeding value of oats grain

Table 9: Hull lignin rating of a range of oat varieties—low is better for ruminant feed value

Low	Medium	Medium-high	High
Bass, Bimbil, Brusher, Carbeen, Cooba, Eurabbie, Graza 68, Mannus, Mitika, Mulgara, Nile, Tungoo, Wintaroo, Yarran, Yiddah	Blackbutt (variable), Graza 80, Quoll	Euro, Potoroo, Wandering	Bannister, Carrolup, Coolabah, Dawson, Drover, Dunnart, Echidna, Forester, Genie, Graza 50, Kangaroo, Mortlock, Nugene, Possum, Taipan, Williams, Wombat, Yallara

Table 10: Feedlot performance (117 days)

	Barley*	Oats*
Daily feed intake (kg)	13.50	13.42
Average daily gain (kg/day)	1.39	1.35
Feed conversion ratio (kg DM / kg LW)	9.72	10.02

10 A Rayner (2007) Using oats as an alternative grain in opportunity feedlot rations. Primefacts No. 381. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0017/101339/Using-oats-as-an-alternative-grain-in-opportunity-feedlot-rations.pdf

More information

[NSW DPI: Using oats as an alternative grain in opportunity feedlot rations]

[NSW DPI: Yield and digestibility of legume and oat forages]

[NSW DPI: Feed energy]

[GRDC Ground Cover: Oats]

[Agriculture Victoria: Harvesting forage cereals]

[NSW DPI: Successful silage]

Table 11: A guide to the metabolisable energy content of Australian grains based on their crude protein (CP) content (dry matter basis)

Source: Derived from the NSW Agriculture Feed Evaluation Database.[11]

CP (%)	Metabolisable energy (MJ/kg) Sorghum	Maize	Oats	Wheat	Barley
6	10.2	11.4	12.4	12.7	13.2
7	10.6	12	12.9	13	13.5
8	10.8	12.4	13.1	13.4	13.7
9	11	12.8	13.3	13.6	13.9
10	11.1	13	13.6	13.8	14
11	11.4	13.2	13.7	14.1	14
12	11.5	13.3	13.8	14.2	14.2
13	11.6	–	13.9	14.3	14.2
14	11.7	–	14	14.4	14.3
15	11.9	–	14.1	14.5	14.3
16	12	–	14.1	14.5	14.3

2.1.5 Hay

Australia exports up to 700,000 tonnes of oaten hay a year.[12]

2.1.6 Silage

Table 12: Yield and ME content of triticale, oats and wheat silage cut at the boot, anthesis, milk and soft dough stage at Terang, Victoria

Crop	Stage	Yield (t DM/ha)	ME (MJ ME/kg DM)
Triticale	Boot	5.1	10.4
	Anthesis	11.9	8.6
	Milk	13.8	8.7
	Soft dough	17.9	8.8
Oats	Boot	7.5	10.4
	Anthesis	7.7	10.5
	Milk	10.3	9.9
	Soft dough	10.4	8.9
Wheat	Boot	7.9	10.2
	Anthesis	8.4	9.6
	Milk	10.1	9
	Soft dough	10.9	9.3

2.1.7 Grazing

The ideal stage to start grazing is when plants are well anchored and the canopy has closed. Continuous grazing may be better for fattening stock than rotational grazing. Maintain adequate plant material to give continuous and quick regrowth (e.g. a minimum of 1000–1500 kg/ha of dry matter). For the best recovery after grazing, do not graze below 5 cm for prostrate varieties, and below 10 cm for more erect types. The higher grazing height is particularly important with erect growing varieties. Over-grazing greatly reduces the plant's ability to recover.

11 B. Granzin (2003) Energy supplements for dairy cows. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/livestock/dairy-cattle/feed/research/energy

12 PIRSA. National Oat Breeding Program. Case Studies. Primary Industries and Regions SA, http://pir.sa.gov.au/case_studies/case_study/sardi/national_oat_breeding_program

Financial returns from grazing can be based on:

- Changes in body weight throughout the grazing period. Weight gains of 1.2 kilograms per head per day for steers, and 200 grams per head per day for lambs are common;
- Stock value before and after grazing;
- Current agistment rates for stock; and
- Hand feeding costs for the same period.

On the tablelands and slopes, grazing oats significantly reduces the grazing pressure on pastures and can often reduce the necessity for hand feeding during winter.

On the slopes and plains, grazing oats enables autumn spelling of lucerne pastures.[13]

2.2 Planting seed quality

Use plump good quality seed from paddocks with a good fertiliser history, uniform in size, not cracked or broken, stored in dark cool dry conditions (not more than one year old) and free from pests and disease.

Seed should have a high percentage germination, free from weed seeds and inert rubbish.[14]

2.2.1 Seed size

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

Seed size is usually measured by weighing 1000 grains, known as the 1000-grain weight. Sowing rate needs to vary according to the 1000-grain weight for each variety, in each season, in order to achieve desired plant densities. To measure 1000-grain weights, count out 10 lots of 100 seeds, then weigh. When purchasing seed, remember to request the seed analysis certificate, which includes germination percentage, and the seed weight of each batch where available. The coleoptile is the pointed, protective sheath that encases the emerging shoot as it grows from the seed to the soil surface. Coleoptile length is an important characteristic to consider when planting a oat crop, especially in drier seasons when sowing deep to reach soil moisture.

2.2.2 Seed germination and vigour

Seed germination and vigour greatly influence establishment and yield potential.

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

- water absorption (imbibition)
- activation
- visible germination [15]

[13] NSW DPI (2015) Winter crop variety growing guide 2015. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

[14] DAFWA (2014) Oats: seeding and establishment. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-seeding-and-establishment?page=0%2C3

[15] 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

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

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

However, seeds lose vigour before they lose the ability to germinate. That is why seed lots that have similar, high germination values can differ in their physiological age (the extent of deterioration) and so differ in seed vigour and therefore the ability to perform. [16]

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

Request a copy of the germination and vigour analysis certificate from your supplier for purchased seed. For seed stored on-farm, you can send a sample to a laboratory for analysis (http://aseeds.net.au/seed-testing).

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

- Use a flat, shallow, seeding tray (about 5 cm deep). Place a sheet of newspaper on the base to cover drainage holes, and fill with clean sand, potting mix or freely draining soil. Ideally, the test should be done indoors at a temperature of ~20°C or lower.
- Alternatively, lay a well-rinsed plastic milk container on its side and cut a window in it, place unbleached paper towels or cotton wool in the container, and lay out the seeds. Moisten and place on a window-sill. Keep moist, and count the seeds as outlined below.
- Randomly count out 100 seeds, do not discard damaged ones, and sow 10 rows of 10 seeds at the correct seeding depth. This can be achieved by placing the seed on the smoothed soil surface and pushing in with a pencil marked to the required depth. Cover with a little more sand/soil and water gently.
- Keep soil moist but not wet, as overwatering will result in fungal growth and possible rotting.
- After 7–10 days, the majority of viable seeds will have emerged.
- Count only normal, healthy seedlings. If you count 78 normal vigorous seedlings, the germination percentage is 78%.
- Germination of 80% is considered acceptable for cereals.
- The results from a laboratory seed-germination test should be used for calculating seeding rates. [17]

2.2.3 Disease

Grain retained for seed from a wet harvest is more likely to be infected with seed-borne disease. It is also more likely to suffer physical damage during handling, increasing the

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

17 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

potential for disease. Seed-borne disease generally cannot be identified from visual inspection, so requires laboratory testing. [18]

2.2.4 Seed storage

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

- Temperature <15°C. High temperatures can quickly reduce seed germination and quality. This is why germination and vigour testing prior to planting are so important in the northern region.
- Moisture control. Temperature changes cause air movements inside the silo, carrying moisture to the coolest parts of the seed. Moisture is carried upwards by convection currents in the air; these are created by the temperature difference between the warm seed in the centre of the silo and the cool silo walls, or vice versa. Moisture carried into the silo head space may condense and fall back as free water, causing a ring of seed to germinate against the silo wall.
- Aeration slows the rate of deterioration of seed with 12.5–14% moisture. Aeration markedly reduces grain temperature and evens out temperature differences that cause moisture movement.
- No pests. Temperature <15°C stops all major grain insect pests from breeding, slowing down their activity and causing less damage.[19]

2.2.5 Safe rates of fertiliser sown with the seed

Crop species differ in tolerance to N fertiliser when applied with the seed at sowing. Recent research work funded by Incitec Pivot Fertilisers has shown that the tolerance of crop species to ammonium fertilisers placed with the seed at sowing is related to the fertiliser product (ammonia potential and osmotic potential), the application rate, row spacing and equipment used (such as a disc or tine), and soil characteristics such as moisture content and texture. [20]

The safest application method for high rates of high ammonium content fertilisers is to place them away from the seed by physical separation (combined N–phosphorus products) or by pre- or post-plant application (straight N products). For the lower ammonium content fertilisers (e.g. mono-ammonium phosphate (MAP)) close adherence to the safe rate limits set for the crop species and the soil type is advised. [21]

High rates of N fertiliser applied at planting in contact with, or close to, the seed may severely reduce seedling emergence. If a high rate of N is required, then it should be applied pre-planting or applied at planting but not in contact with the seed (i.e. banded between and below sowing rows). Rates should be reduced by 50% for very sandy soil and increased by 30% for heavy-textured soils or if soil moisture conditions at planting are excellent. [22]

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.

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

19 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

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

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

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

More information

GRDC: Care with fertiliser and seed placement

Table 13: Suggested safe rates (kg/ha) of some nitrogen fertilizer products sown with oat seed at planting

Row spacing Maximum nitrogen rate Urea DAP MAP

Row spacing		Maximum nitrogen rate	Urea	DAP	MAP
cm	in				
18	7	30	65	158	230
36	14	15	33	79	115

SECTION 3

Planting

3.1 Seed treatments

Seed dressing and in-furrow fungicides contain active ingredients for the control or suppression of seed-borne diseases, some fungal root rots and insect pests in cereal crops.

At seeding, fungicides can be applied to seed (seed dressing) or applied in soil (coated on compound fertiliser or mixed with liquid fertiliser and applied in-furrow) to be taken up by cereal seedlings. Seed-dressing fungicides provide protection from seed-borne diseases such as smuts and bunts. Some products also suppress or control fungal root rots such as Pythium root rot, Rhizoctonia root rot and take-all. Some seed dressing and/or in-furrow products suppress early foliar diseases such as rusts, whilst others can provide either control or suppression of insect pests such as aphids and mites.

Seed dressing and in-furrow fungicides may contain one active ingredient or more and they are marketed under many trade names. When choosing seed-dressing or in-furrow fungicides, consider the range of diseases that threaten your crop. Consult product labels for registrations, the Australian Public Chemical Registration Information System at the Australian Pesticides and Veterinary Medicines Authority (APVMA) or InfoPest. Reassess your disease risk before seeding by looking at seasonal forecasts, green-bridge updates and crop disease forecasts for your local area.

Paddock and farm history is also an important consideration when determining disease risks. Factors that affect potential disease levels include the previous year's crop in the paddock and the disease status of that crop.

For a range of dressings for control of covered and loose smuts in oats, see the NSW Department of Primary Industries (DPI) publication: Winter crop variety sowing guide 2015 (pp. 122–123, Cereal seed dressings). [1]

For seed dressings for aphid control in cereals, consult NSW DPI publications: Insect and mite control in field crops 2013 (p. 92, table 37), and Winter crop variety sowing guide 2015 (p. 123, Cereal insecticide seed dressings for aphid and *barley yellow dwarf virus*). [2,3]

3.1.1 Cautions about using fungicide seed dressings

Read and follow directions on fungicide labels carefully.

In some situations, certain fungicide seed dressings (e.g. triazoles) may reduce coleoptile length, which could result in leaves growing under the soil surface and not

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

2 K Hertel, K Roberts, P Bowden (2013) In sect and mite control in field crops. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

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

emerging, particularly if short-coleoptile varieties and/or deep sowing are used. Check chemical labels for this information.

Coleoptile shortening may also result from use of dinitroaniline herbicides (trifluralin, pendimethalin, oryzalin). Take care where coleoptile-shortening seed dressings are used together with these herbicides, particularly if it is difficult to obtain good depth control of herbicide incorporation and seed placement, such as in sandy soils. [4] Take into consideration variation in coleoptile length between varieties if deep sowing and triazole seed dressings are to be used.

3.2 Time of sowing

Except in very high Tablelands of New South Wales, January and February sowings should be avoided. Hot conditions, soil temperature consistently >25°C, and rapidly drying soils can cause patchy establishment.

Optimum sowing times are shown for each variety in the respective zones (Table 1). Sowing later than recommended increases the risk of lower yields. In wet, acid soil conditions, sow grain-only varieties at the earliest recommended time. [5]

Sowing time for grain crops is a balance between having the crop flowering soon after the last heavy frost, and being early enough to allow adequate grainfill before the onset of moisture stress and heat in spring.

For grazing crops, management is different. The crop needs to be producing biomass as quickly as possible to fill potential autumn gaps in feed supply, and then locked up to get maximum grain recovery. Sufficiently cool soil temperature at sowing, and adequate moisture, are usually the limitations to sowing time for grazing crops.

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

4 K Jayasena, C Beard, GJ Thomas, A Hills (2016) Seed dressing and in-furrow fungicides for cereals in Western Australia. Department of Agriculture and Food WA, https://www.agric.wa.gov.au/barley/seed-dressing-and-furrow-fungicides-cereals-western-australia?page=0%2C2#smartpaging_toc_p2_s7_h2

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

Table 1: Sowing times for oats in regions of New South Wales

Variety	January		February				March				April				May				June		
	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
Higher Tablelands/Tablelands: Dual-purpose – grazing and/or grain recovery																					
Bass, Blackbutt, Nile	>	★	★	★	★	★	★	★	★	★	<	<									
Eurabbie			>	>	★	★	★	★	★	★	★	★	★	★	<	<					
Bimbil, Mannus					>	>	★	★	★	★	★	★	★	★	<	<					
Tablelands/Slopes: Dual-purpose – grazing and/or grain recovery																					
Blackbutt					>	★	★	★	★	<	<	<	<								
Eurabbie					>	★	★	★	★	★	★	<	<								
Cooba#						>	★	★	★	★	<	<	<	<	<						
Bimbil, Mannus, Yiddah								>	★	★	★	★	<	<	<						
Coolabah#, Yarran#									>	★	★	★	★	<	<						
Slopes/Plains: Dual-purpose – grazing and/or grain recovery																					
Cooba#, Eurabbie						>	★	★	★	★	★	<	<	<	<						
Bimbil, Mannus, Yiddah								>	★	★	★	★	★	★	<	<	<				
Coolabah#, Yarran#									>	★	★	★	★	★	<	<	<				
Tablelands/Slopes grain only																					
Bannister, Mitika, Mortlock#, Possum, Williams, Wombat, Yarran #															>	★	★	★	<	<	<
Slopes/Plains grain only																					
Bannister, Mitika, Possum, Williams, Wombat, Yallara															>	★	★	★	★	<	<
Mortlock#, Yarran#															>	★	★	★	★	★	<

> Earlier than ideal, but acceptable.
★ Optimum sowing time.
< Later than ideal, but acceptable.
Outclassed varieties

Warning: High soil temperatures (> 25°C) with early sowings may reduce germination and establishment.

Although outlying severe frosts cannot be mitigated, the risk of seasonal frosts at flowering needs to be assessed and balanced. Frost damage is a major consideration and the risk cannot be eliminated; therefore, the potential for higher yields from earlier sowings needs to be balanced against the risk of frost damage at flowering. There are two ways of doing this:

1. In areas where the risk of frost is high (i.e. low-lying paddocks, regions with lower winter temperatures such as the Slopes to the east of the region), sow later than the suggested optimum sowing period. As a rule-of-thumb, three days' difference at planting makes one day of difference at heading.
2. Change varieties. Use maturity differences to have the crop flowering at a time when the seasonal frost risk is acceptable.

With the wide range of oat varieties available, it is possible to choose a variety suitable for sowing from the beginning of autumn through to as late as early winter. Avoid early sowings of leaf-rust-susceptible varieties and varieties sensitive to very warm soils. [6]

The optimum planting time for forage oats is mid-March to June in southern Queensland and northern New South Wales, and early April to June in central

[6] Pacific Seeds (2006) Oats agronomy guide. Yearbook 2006/2007. Pacific Seeds, https://www.pacificseeds.com.au/images/stories/winter_forage/information/yearbookoatsagronomy2006.pdf

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Queensland. Very early plantings (January to early March) should be avoided, to minimise the risk associated with leaf rust. Planting too early or late also reduces forage yield. Late planting will hasten maturity and reduce the potential for multiple grazings. However, late planting may be suitable for hay production to avoid problems associated with lodging. Oats for grain and seed are best planted in May–June.

Forage varieties can be planted from early March to produce feed in autumn and early winter when the typical 'feed gap' occurs.

3.3 Soil temperature at sowing

Soil temperature at sowing time is an important consideration. The optimum soil temperature for the germination and establishment of oats is 15–25°C. If the soil is too warm, germination will be delayed and plant establishment may be very poor. Oats can germinate at higher soil temperatures that can wheat or barley. [7] However, at a soil temperature of 35°C, oats will not usually germinate.

Varieties that can be successfully sown into soil temperatures >25°C should be utilised under such conditions. These include Drover⸙, with good warm-soil emergence (up to 28°C), and Taipan⸙ and Comet⸙, up to 29°C.

Soil temperature will vary during the day, and for oats, the maximum soil temperature is the most useful measure. This can be established mid–late afternoon.

Warm soil reduces the plant's coleoptile length [8], and warm soils dry out quicker than cooler soils, which means a need for deeper sowing. Oats generally have a longer coleoptile than other cereals, particularly wheat, and are therefore more suited to sowing into warmer soils.

More information

Research paper: Temperature affects germination, mesocotyl length and coleoptile length of oats genotypes

DAF Qld: Forage oat variety guide 2015

NSW DPI: Cropping to fill the feed gap

Rural Weekly: Is it too early to be planting oats

Pacific Seeds: Oats agronomy guide 2006/07

FAQ

3.4 Targeted plant population

Establishment of optimum plant population is essential to achieve the maximum possible yield. The desired plant density depends on yield potential and the purpose for which the crop is being grown (i.e. grain *v.* grazing). A higher plant population can improve crop competitiveness against herbicide-resistant ryegrass.

High seeding rates give rapid growth rates and high forage yields. Use high rates where dense weed populations are expected, when conditions are likely to be wet during winter, in low pH soils, or if seed quality is substandard.

Suggested sowing rates for oats in New South Wales are as follows:

1. Higher Tablelands, Tablelands, Slopes: 80–120 kg/ha, grazing and grain; 60–80 kg/ha, grain-only
2. Slopes, Plains: 60–80 kg/ha, grazing and grain; 40–60 kg/ha, grain-only.
3. Early sown—grazing only: 100–130 kg/ha
4. Irrigation: 100–150 kg/ha, grazing and grain; 80–120 kg/ha, grain-only
5. Hay production (seeding rates are 30–50% higher than grain crops in the same region): 60–100 kg/ha dryland; 80–140 kg/ha irrigated [9]

[7] B Haskins (2006) Cropping to fill the feed gap. Agriculture Today. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/archive/agriculture-today-stories/ag-today-archives/agriculture_today_march_2006/2006-003/cropping_to_fill_the_feed_gap

[8] BJ Radford, AJ Key (1993) Temperature affects germination, mesocotyl length and coleoptile length of oats genotypes. *Australian Journal of Agricultural Research* 44, pp. 677–688, http://www.publish.csiro.au/paper/AR9930677

[9] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

More information

[DAFWA: Oats: seeding and establishment]

[DAFWA: Oats: hay essentials]

Reasons to increase plant density include:

- Hay production: to help plants to compete against weeds and to produce finer stems as required for the export market. Target 30–50% higher plant numbers than grain crops. Finer stems also dry quicker.
- Dwarf varieties: Plump-grained varieties can be sown at higher density.
- Seedling emergence and establishment are likely to be reduced.
- The crop is to be grazed.
- Plant tillering is expected to be low because of variety or soil fertility effects.
- Delays to sowing are likely. [10]

3.4.1 Row spacing

Row spacings will partly depend on location in the Northern Region and the availability of machinery, although most growers use 33 cm. Higher rainfall areas traditionally have narrower row spacings because of higher yield potentials. In most cases, growers do not have the option to change row spacings on machinery to suit individual crop needs for winter crops.

The advantages of wider rows:

- reduced trampling losses during grazing
- a more open crop canopy that will be less favourable to rust development
- potential to reduce sowing rate [11]
- greater ability to sow through standing stubble

The advantages of narrow rows:

- greater competition against weeds, especially in the presence of resistant weeds
- fewer issues with viruses
- higher grain yields
- thinner plant stems in a crop destined for oaten hay production

More information

[Pacific Seeds: Oats agronomy guide]

For hay crops expected to yield >4 t/ha, rows should be sown no further than 25 cm apart, and preferably <20 cm apart. This will give good ground coverage by plants so that the windrow can be held off the ground to improve air circulation and reduce staining. [12]

3.5 Calculating seed requirements

Seed size varies significantly between oat varieties and seasons; therefore, it is important to measure the 1000-grain weight of the selected variety to calculate the required seeding rate. Seeding rates shown in Table 2 should be used as a guide only, and growers should calculate their own seeding rates based on 1000-seed weight, target plant population and seed establishment percentage. [13]

Calculate seeding based on seed size, target plant population and calculated germination per cent. Work in terms of plants per square metre rather than kilograms per hectare (kg/ha) because grain size and weight varies between crops, varieties and seasons.

[10] DAFWA (2014) Oats: seeding and establishment. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-seeding-and-establishment?page=0%2C1

[11] Pacific Seeds (2006) Oats agronomy guide. Yearbook 2006/2007. Pacific Seeds, https://www.pacificseeds.com.au/images/stories/winter_forage/information/yearbookoatsagronomy2006.pdf

[12] DAFWA (2014) Oats: seeding and establishment. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-seeding-and-establishment?page=0%2C2

[13] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

To determine the average grain weight, count and weigh 1000 seeds of the graded sample. The seed rate calculation is:

Seed rate (kg/ha) = (target plant density (plants/m^2) x average grain weight (mg)) ÷ expected establishment (%)

For example, if the desired plant population is 240 plants/m^2, the average grain weight is 40 mg and expected establishment is 80%, the calculation is: (240 x 40)/80 = 120 kg/ha.

A tip is to count 200 seeds and multiply by five.

Agronomist's view

Table 2: Examples of seed rates calculated on the basis of target plant population, seed weight and establishment percentage [14]

Average seed weight (mg)	160 plants/m^2	240 plants/m^2	320 plants/m^2
33	66	99	132
35	70	105	140
37	74	111	148
39	78	117	156

More information

DAFWA: Oats: seeding and establishment

Heritage Seeds: Williams⑴ oat

3.6 Sowing depth

Sowing plump seed at the right depth is an important first step to achieving vigorous, healthy seedlings. Planting should be deep enough to provide uniform coverage of the seed and to help maintain moist conditions for germination and protect the seed from hot soil conditions.

A sowing depth of 3–5 cm is ideal, but oats can be sown as deep as 7 cm if moisture-seeking. [15]

Oat seedlings emerge by elongation of the mesocotyl and coleoptile (in wheat and barley it is only through elongation of the coleoptile), which is why oats can safely be sown deeper than wheat and barley. Coleoptile and mesocotyl length are temperature-dependent, and early sowing into warmer soils will result in longer coleoptiles and mesocotyl than with later sowings in winter. [16] Note, however, that sowing into soils that are too warm can reduce the coleoptile length.

Sowing too shallow may:

- place the seed in dry soil or in moisture that is retreating down the profile, causing failure to emerge
- cause shallow crown depth, resulting in lodging of plants when soil is very wet and in high winds
- make plants more vulnerable to pre-emergent herbicides such as diuron
- expose the seeds to hotter soil temperatures during germination

Consequences of deep sowing can include:

- delayed or no seedling emergence
- emerging seedlings that are weaker, limp and easily damaged by wind and insects

14 DAFWA (2014) Oats: seeding and establishment. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-seeding-and-establishment?page=0%2C1

15 P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

16 DAFWA (2014) Oats: seeding and establishment. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-seeding-and-establishment?page=0%2C2

- reduced root development, making plants more susceptible to root diseases
- delayed plant development and tillering
- reduced competitiveness with emerging weeds

Use press-wheels to compress the soil directly above the seed for even distribution during seeding. When using standard tined seeders without press-wheels, the seed is often spread through a depth of 2–3 cm with the occasional seed left on the soil surface.

More information

NSW DPI: Winter crop variety guide 2015

DAF Qld: Planting and nutrition of oats

DAF Qld: Forage oat variety 2015

Pacific Seeds: Oats agronomy guide

SECTION 4

Plant growth and physiology

4.1 Dormancy affecting germination and emergence

The dormant period is generally short in oats — from a few days to several weeks.

4.2 Plant growth stages

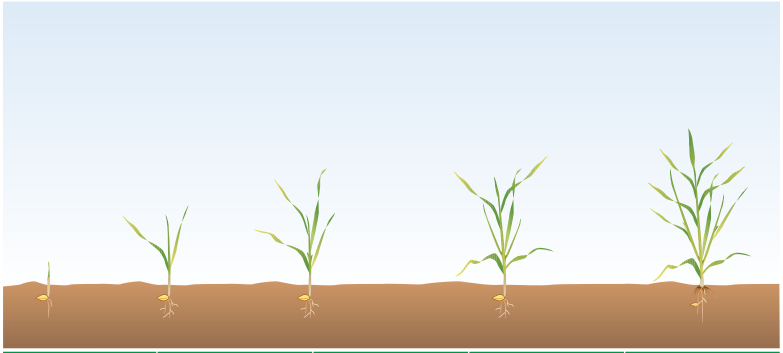
A growth stage key provides farmers, advisers and researchers with a common reference for describing the crop's development. Management by growth stage is critical to optimise returns from inputs such as N, plant growth regulator, fungicides and water.

4.2.1 Zadoks Cereal Growth Stage Key

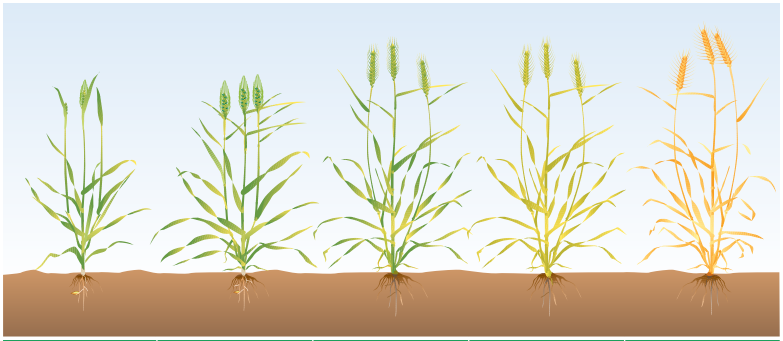
This is the most commonly used key to growth stages for cereals, in which the development of the cereal plant is divided into 10 distinct development phases covering 100 individual growth stages. Individual growth stages are denoted by the prefix GS (growth stage) or Z (Zadoks), for example, GS39 or Z39.

The principal Zadoks growth stages (Figure 3) used in relation to disease control and N management are those from the start of stem elongation through to early flowering: GS30–GS61.

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18



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



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

Figure 1: Zadoks growth stages

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

This period is important for both timing of N application and protection of key leaves. In order to ensure the correct identification of these growth stages, plant stems are cut longitudinally, so that internal movement of the nodes (joints in the stem) and lengths of internodes (hollow cavities in the stem) can be measured.

Leaf dissection at GS32 and GS33

This is a method for determining which leaves are emerging from the main stem prior to the emergence of the flag leaf. Knowing which leaves are present is critical if fungicide use is to be optimised to protect leaves.

The Zadoks Cereal Growth Stage Key does not run chronologically from GS00 to GS99; for example, when the crop reaches three fully unfolded leaves (GS13), it begins to tiller (GS20) before it has completed four, five and six fully unfolded leaves (GS14, GS15, GS16).

It is easier to assess main stem and number of tillers than it is the number of leaves (due to leaf senescence) during tillering. The plant growth stage is determined by main stem and number of tillers per plant; for example, GS22 is main stem plus two tillers and GS29 is main stem plus nine or more tillers.

In Australian cereal crops, plants rarely reach GS29 before the main stem starts to stem elongate (GS30). Because of growth stages overlapping, it is possible to describe a plant with several growth stages at the same point in time. For example, a cereal plant at GS32 (second node on the main stem) with three tillers and seven leaves on the main stem would be at GS32, 23, 17, yet practically would be regarded as GS32, since this describes the most advanced stage of development.

Note: After stem elongation (GS30), the growth stage describes the stage of the main stem; it is not an average of all the tillers. This is particularly important with timing fungicide; for example, GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged. [1]

More information

More Information on oat diseases, especially in hay production, can be found in:

Gordon M Murray (2007) Review of Diseases of Oats for Hay: Current and Future Management Part II: Identification and control options for the diseases of importance, A report for the Rural Industries Research and Development Corporation. RIRDC. https://rirdc.infoservices.com.au/downloads/07-122

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

SECTION 5

Nutrition and fertiliser

FAQ

Oats have traditionally been considered a low-input crop and have generally been grown on paddocks with lower soil fertility. The development of higher yielding grain and hay varieties, combined with greater emphasis on grain and hay quality from both export and domestic markets, means that nutrient management has to be more carefully considered when growing oats.

Nutrient requirements and fertiliser rates are similar to those recommended for nutrition of other cereal crops. Essential at sowing is a starter fertiliser containing nitrogen (N) and phosphorus (P), and possibly sulfur (S).

Nutrition requirements for N, P and potassium (K) in oat grain crops are similar to those recommended for wheat or barley.

Figure 1: Application of nutrients is required to optimise production either on an annual basis for nutrients such as N and P or less frequently for micronutrients such as copper (Cu) and zinc (Zn). (Photo: Nicole Baxter)

It is important for growers to use both soil testing and tissue testing to ensure the crop nutrient status is adequate for plant growth.

Apply fertiliser at above the normally recommended rates to crops used for grazing and grain, as they have a longer vegetative period than grain-only crops.

5.1 Crop removal rates

Oat crops, particularly oaten hay, remove significant quantities of all the major nutrients.[1]

Table 1: Comparison of the average quantity of nutrients removed (kg/ha) per tonne of grain production for a range of crops [2]

Crop type	Nitrogen	Phosphorus	Potassium	Sulfur
Wheat	21	3.0	5	1.5
Triticale	21	3.0	5	1.5
Barley	20	2.7	5	1.5
Oats	17	2.5	4	1.5

5.2 Soil testing

Soil test information can be used to support decisions about fertiliser rate, timing and placement. Soil testing is the only quantitative nutrient information that can be used to predict yield response to nutrients.

Soil samples should be taken close to sowing so summer mineralisation rates can be captured, but with enough lead time so fertilisers and other inputs can be ordered and be on-farm in time for the sowing operation.

Incorporate deep sampling of N and S to determine N budgeting for the season. This may include the pre-drilling of N pre-sow and N at sowing or topdressing as the season progresses. For growers relying on topdressing to supply additional N, soil-sample in-crop during early crop development or take plant tissue tests (i.e. cereals during early tillering) with sufficient time to allow timely topdressing (i.e. cereals before GS31).

Choose a laboratory that has Australasian Soil and Plant Analysis Council (ASPAC) certification for the tests they offer. National Association of Testing Authorities (NATA) accreditation is also desirable.

Regular sampling of paddocks (e.g. every three years for most nutrients, except for N, which should be every year) allows monitoring of fertility trends over time. Sampling points should be GPS recorded, so subsequent samples are taken from exactly the same place. [3]

Appropriate soil tests for measuring soil extractable or plant available nutrients are:

- bicarbonate extractable P (Colwell-P), to assess easily available soil P
- acid extractable P (BSES-P), to assess slower release soil P reserves and the build-up of fertiliser residues (not required annually)
- exchangeable K
- KCl-40 extractable S or MCP-S
- 2M KCl extractable mineral N, to provide measurement of nitrate-N and ammonium-N

Other measurements that both aid the interpretation of soil tests and illustrate soil properties that may influence nutrient uptake include:

- soil carbon or organic matter content
- phosphorus buffering index (PBI)
- soil salinity measured as electrical conductivity

1 DAFWA (2015) Oats: fertilisers and plant nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

2 Agriculture Victoria (2008) Establishing forage cereals, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/forage-cereals/establishing-forage-cereals

3 GRDC (2013) Better fertiliser decisions for crop nutrition. Northern, Southern and Western Regions. Crop Nutrition Fact Sheet, GRDC, 4 November 2013, http://grdc.com.au/Resources/Factsheets/2013/11/Better-fertiliser-decisions-for-crop-nutrition

More information

[GRDC Fact Sheet: Soil testing for crop nutrition (Northern Region)]

[GRDC Fact Sheet: Better fertiliser decisions for crop nutrition]

[GRDC Update Papers: The what where and why of soil testing in the northern region]

- chloride and other exchangeable cations, including aluminium
- soil sodicity
- cation exchange capacity (CEC)
- dispersion
- exchangeable sodium percentage (ESP)

The most common soil-sampling depth for nutrient analysis is 0–10 cm, or 0–15 cm for broadacre crops. This layer is chosen because nutrients, especially P, and plant roots are concentrated within this layer. [4] Deep soil testing is a must when sampling for N and S, due to their mobility in the soil. Depths should be to 90–120 cm.

Some work is being conducted on the rundown of the immobile nutrient P at depth. [5] Soil testing every three years in the 10–30 cm band may be beneficial with this nutrient to establish a baseline.

5.3 Plant and/or tissue testing for nutrition levels

Figure 2: Oat crops remove significant quantities of all major nutrients. (Photo: DAFWA)

Oat crops, particularly oaten hay, remove significant quantities of all the major nutrients. It is, therefore, important for growers to use both soil testing and tissue testing to ensure the crop nutrient status is adequate for plant growth. [6]

Plant tissue testing is an underutilised tool for diagnosing hidden nutritional deficiencies in crops. Growers are urged to consider tissue testing to diagnose macronutrient and micronutrient deficiencies.

Unlike macronutrients such as nitrogen and phosphorus, micronutrients, or trace elements, cannot be reliably assessed using soil tests alone due to their low concentration in the soil. Because of this, tissue testing is a good tool to confirm a suspected micronutrient deficiency.

The micronutrients most likely to limit production in Australian soils are zinc (Zn), copper (Cu), manganese (Mn), molybdenum (Mo) and boron (B). [7]

4 GRDC (2014) Soil testing for crop nutrition. Northern Region. Crop Nutrition Fact Sheet, GRDC, 20 January 2014, http://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-North

5 S Jeffrey (2015) Deep P applications trialled in Central West NSW. GRDC, 29 September 2015, http://grdc.com.au/Media-Centre/Media-News/North/2015/09/Deep-P-applications-trialled-in-Central-West-NSW

6 DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

7 R Barr (2015) Tissue testing a health check-up for micronutrients. Micronutrients Fact Sheet, GRDC, 11 June 2015, http://www.grdc.com.au/Media-Centre/Media-News/South/2015/06/Tissue-testing-a-health-checkup-for-micronutrients#sthash.5lgdYcbC.0hpbznl1.dpuf

More information

GRDC Plant tissue testing an underutilised tool for diagnosing hidden hunger in crops

GRDC: Tissue testing a health check-up for micronutrients

GRDC Videos

Video: GRDC Plant tissue testing uncovering hidden hunger

The successful use of plant tissue analysis depends on sampling the correct plant part at the appropriate growth stage as nutrient concentration can change during the life cycle of the oat plant.

For these reasons, critical tissue concentrations should be associated specifically with defined stages of plant growth or plant part rather than growth periods (i.e. days from sowing). If the lab you are using has a guide or instructions for sample collection, follow them as the sample will be assessed against these sorts of interpretative guidelines. [8]

5.4 Nitrogen

5.4.1 The importance of nitrogen management

Nitrogen (N) is largely responsible for setting up the yield potential of the crop. N is required for tiller development and required by plants to create protein. The N for plant growth is supplied from both the soil and from N fertiliser application. N is taken up by the oat plant when it is in an inorganic form (as either ammonium or nitrate). In the soil over 98% of the N is in an organic form that cannot be taken up by the oat plant until it is mineralised. A large proportion of the oat plant's requirement for N is supplied by the soil. Where the available N supply from the soil is inadequate for optimum yield and quality, N fertiliser is required. Soil testing helps estimate the amount of N already available in the soil. Soil type, cropping history, yield potential and the season are important factors to consider in N management decisions.

The amount of N fertiliser required to grow a grain or oat hay can be estimated from the N budget, which is calculated accounting for yield, protein levels, soil mineralisation of N, available soil supplies and additional N fertiliser to be applied. A 2 t/ha oat crop will require 60–70 kg N in total, assuming a nitrogen use efficiency (NUE) of 50%.

The amount of N required will be modified by seasonal conditions and the oat variety and usage. The timing of N in a grazing crop may differ from that for a grain or hay crop. For a grazing crop it is all about fast, high-protein feed so grazing can commence quickly in the autumn. A similar approach in a hay crop may lead to lodging of the oat plants.

In wet seasons, leaching of N can occur, particularly in sandy soils. To maximise hay quality any late N should be applied between tillering (Z25) and stem elongation (Z31). Applying N too late (later than Z33) causes nitrates to accumulate in the plant dry matter, reducing hay quality. For grain yield, profitable responses to N application have been found up to 10 weeks after sowing. [9]

Deficiency:- what to look for

Paddock

- N deficiency may result in light-green to yellow-orange plants, particularly on sandy soils, or unburnt header or swathe rows.
- Double-sown areas have fewer symptoms if nitrogen fertiliser was applied at seeding.

Plant

- Young plants may be short, thin and pale green, with fewer tillers.
- Symptoms first occur on the oldest leaf and then progressively younger leaves, with symptoms progressing to tip reddening and death, beginning at the base until the entire leaf is brown and withered.

8 GRDC (2010) Plant tissue testing: an under-utllised tool for diagnosing hidden hunger in crops. GRDC Update Papers, 17 September 2010, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/PLANT-TISSUE-TESTING-AN-UNDER-UTILISED-TOOL-FOR-DIAGNOSING-HIDDEN-HUNGER-IN-CROPS - sthash.BsTMIP6V.sZxhcSgA.dpuf

9 DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

- As deficiency becomes more severe, leaf tips become orange-red. As tissue dies it turns dark brown and leaf margins often roll upwards to form a tube.
- Stems may become red.
- N-deficient plants develop more slowly than healthy plants, but maturity is not greatly delayed.
- Reduced head size, grain yield and protein levels result. [10]

Table 2: What else could it be [11]

Condition	Similarities	Differences
Waterlogging and salinity	Pale plants with oldest leaves most affected	Root browning or lack of feeder roots and wet soil
Molybdenum deficiency	Pale poorly tillered plants	Affects the middle leaves first and causes white heads, shrivelled grain and delayed maturity

Red tipping

Red-tipped leaf is an extreme form of foliar disorder in oats. It is associated with deficiency in N, P, K, Zn and S in the soil. N deficiency is the most common cause. Red-tipping is not a symptom of rust infection.

The reddish colour, seen mostly on mature leaves, is caused by the presence of anthocyanin. The intensity of the redness varies with the season. Early stages of the disorder show light-yellow veins running parallel to the mid-rib of the leaf. This appears similar to herbicide damage (metsulfuron or Ally®). The entire leaf surface may appear light-yellow. In the later stages the tip turns red. In cold dry winters the colour deepens to almost purple, while in mild wet winters it is a more washed-out orange-red. Affected plants are stunted and are less palatable for livestock.

Red-tipping can be avoided by practising good crop nutrition. In paddocks with a history of this problem, conduct a N audit to ensure the N being supplied meets the demand of the crop. Top dressing can be used to correct the problem, with a good rainfall event required to incorporate the nitrogen. [12]

Nitrogen and hay

Increasing N supply:

- may increase hay yield
- increases hay greenness
- increases stem fibre levels (acid detergent fibre and neutral detergent fibre)
- decreases water soluble carbohydrates (WSC)
- may increase in-vitro digestibility and metabolisable energy slightly
- may sometimes lead to high N levels unacceptable in many hay markets
- interacts with variety for fibre and WSC

Method of N applications also need to be considered. Split applications of N appear important, particularly for hay.

For hay production, do not apply excessive levels of N as that may decrease hay quality by increasing stem fibre levels and decreasing water soluble carbohydrates. Varieties may differ in their response to the amount and method of applied nitrogen. [13]

10 DAFWA (2015) Diagnosing nitrogen deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-oats

11 DAFWA (2015) Diagnosing nitrogen deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-nitrogen-deficiency-oats

12 QDAF (2012) Planting and nutrition of oats. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/oats/planting-information - Red_leaf_tipping

13 DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

Nitrogen and grazing

A good oat crop used for grazing and grain could be expected to use up to 100 kg/ha of N. Both pre-emergent and post-emergent applications of N can be applied in N-deficient situations. With long-season dual-purpose cereals, split applications should be considered. [14]

An application of N after grazing (20–40 units N/ha) will increase the speed of plant recovery, reduce tiller death and increase overall forage yield. [15] This figure should be calculated on a sound N budget.

5.5 Phosphorus

Phosphorus (P) is a vital component of adenosine triphosphate (ATP), the 'energy unit' of plants. ATP forms during photosynthesis and is used to form the beginning of seedling growth through to the formation of grain and maturity. Deficiencies result in slow growth and delayed maturity, decreased hay and grain yields, inferior quality and subsequent lost income.

P is needed during early growth for plant root development and elongation. As such, P needs to be applied at sowing as the crop's peak demand for this nutrient is in the first six weeks of growth. P is very immobile in the soil and hence the product needs to be placed in close proximity to the seed for maximum uptake.

The oat crop response to P will be influenced by the soil's starting levels of P, which can be determined through soil testing. One tonne of oat grain removes 2.5 kg of P from the soil.

Reserves of mineral nutrients such as P have been run down over several decades of cropping with negative P budgets (removing more P than is put back in by fertilisers or crop residues). This trend has accelerated as direct-drill cropping has improved yields and crop frequency, removing even more P from the soil. Consequently, limited P is now constraining yields in parts of the northern grains region, particularly in the vertosols (black and grey cracking clays).

P is largely immobile in the soil, particularly in clay soils, so P applied to the topsoil (0–10 cm) layer will not penetrate into the subsoil.

P is removed from the deeper subsoil layers (10–30 cm) to meet crop demand, especially during dry periods when crop roots cannot access dry topsoil layers and the plant relies almost exclusively on stored subsoil water.

Crops must be able to access P, and potassium (K), another essential but immobile nutrient, from the subsoil. This supply is especially important in the post-seedling stage.

P (and K) levels need to be adequate down to 30–40 cm to drought-proof cropping systems in northern regions, which have a greater reliance on stored soil moisture rather than in-crop rainfall.

It is important to assess the P status of the subsoil periodically. Test the 10–30 cm layer using BSES-P as well as Colwell-P soil tests. [16]

Recent trial work has been conducted throughout the northern region on what is happening to P levels at depth.

Work by Dr Mike Bell has shown that previous trial work has proved that the application of P in the seeding furrow only supplies a crop with a small amount of P, while the crop actually forages for the bulk of its P requirements from other parts of the soil profile.

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14 G Hennessy, B Clements (2009) Cereals for Grazing. NSW DPI Primefact 720, June 2009, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/288191/Cereals-for-grazing.pdf

15 DAF Qld (2015) Forage oat variety guide 2015, https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

16 GRDC (2012) Phosphorus management. Northern Region. GRDC Crop Nutrition Fact Sheet, November 2012,http://grdc.com.au/~/media/Documents/Resources/Publications/Fact-sheets/Phosphorus-Management-Northern-Region-Fact-Sheet.pdf

The northern region differs from other regions in terms of its P situation as crops generally rely on stored soil moisture, which means that roots generally explore deep into the moist subsoil where they can also extract nutrients if they are available.

Deeper parts of the soil profile in the 10–30 cm layer are experiencing nutrient rundown and scientists say that's where P fertiliser placement needs to be explored in the future. [17]

5.5.1 Phosphorus deficiency symptoms

P deficiency results in poor seedling establishment and root development. The deficiency symptoms usually only occur if the deficiency is severe and are more noticeable in young plants, as they have a greater relative demand for P than more mature plants. The tips of the old leaves become dark orange-yellow and this colour moves towards the base, usually along the leaf edges. The affected leaves often have green bases, orange-yellow mid-sections and bright-red or purple tips, and the edges of the leaves are rolled inwards. In severe deficiency, affected areas die and turn red and purple. [18]

Phosphorus deficiency: what to look for

Paddock

- P deficiency reduces seedling establishment and root development. The deficiency symptoms usually occur only if the deficiency is severe and are more noticeable in young plants, as they have a greater relative demand for P than more mature plants.
- Symptoms of P deficiency in oats are usually non-specific and difficult to diagnose in the field. The most noticeable feature in oats is reduced growth and vigour. Acute P deficiency generally occurs when other factors, such as pests, root diseases or dry soil, restrict the plant's ability to access soil P.
- Stripes in the paddock may correspond with fertiliser 'misses' or blockages of the product.

Plant

- Early signs are smaller erect plants with darker leaves and fewer tillers.
- More acute deficiency causes orange to purple colouration on old leaves.
- Orange to red colours, then necrosis, moves down older leaves from the tip. [19]
- Maturity will be delayed.

Table 3: What else could it be [20]

Condition	Similarities	Differences
Dry soil can induce phosphorus deficiency in young plants	Darker leaves and fewer tillers	Symptoms disappear when the soil rewets
Nitrogen deficiency		
Yellow dwarf virus	Progressive reddening and death of older leaves	Yellow dwarf virus is associated with streaks and occurs in patches
Heat stress	Leaf tip browning and necrosis	Associated with a stress event and damage does not progress

[17] S Jeffrey (2015) Deep P applications trialled in Central West NSW. GRDC, 29 September 2015, http://grdc.com.au/Media-Centre/Media-News/North/2015/09/Deep-P-applications-trialled-in-Central-West-NSW

[18] DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

[19] DAFWA (2016) Diagnosing phosphorus deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-oats

[20] DAFWA (2016) Diagnosing phosphorus deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-phosphorus-deficiency-oats

Figure 3: Oat plants with delayed maturity and lack of tillers on the left due to zero P versus adequate P nutrition in the same crop on the right. (Photo: P. Heuston)

More information

DAFWA Diagnosing phosphorus deficiency in oats

DAFWA Oats: fertilisers ad plant nutrition

GRDC Fact Sheet Crop nutrition phosphorus management (Northern Region)

5.6 Sulfur

Sulfur (S) has an important role in the formation of proteins and is essential for the production of chlorophyll. Crops that have a high N requirement must have adequate S to optimise N utilisation and protein synthesis. [21]

The mobile nature of S in the soil, and its capacity to be mineralised through the breakdown of organic matter, makes it difficult to reliably predict when a crop will respond to an application of S.

A synergistic relationship exists between S, N and P that affects plant uptake and efficient use of these nutrients. Too much N can induce S deficiency in plants. Grain yields increase when all three nutrients are in sufficient supply and in the correct ratio.

Most S present in the soil is bound in organic compounds but plants can only take up the mineral sulfate form. Cultivation releases S held in organic matter. In no-till systems soil organic matter breaks down slowly, releasing mineral sulfate for crop use. S mineralisation is low in cooler months, as is root exploration, which can cause temporary deficiency in crops, seen as patches that disappear when the soil temperature increases. Mineralisation is higher in the warmer months and under moist soil conditions. Sulfate adsorption occurs in the soil layers below 10 cm, which can make a significant contribution to crop growth once crop roots have reached the subsoil.

The rate of sulfate leaching is highly variable, depending on seasonal conditions and the water-holding capacity of the soil, and is closely related to the rate of nitrate leaching. These two nutrients are best considered together when planning fertiliser applications at seeding and post-seeding to compensate for their movement down the profile under the current seasonal conditions. [22]

[21] DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

[22] GRDC (2015) Sulfur strategies for western region, http://grdc.com.au/Media-Centre/Hot-Topics/Sulfur-strategies-for-western-region

GRDC Grains Research & Development Corporation

S, like N, is very mobile in the soil and, as such, soil testing for this element needs to be a combination of shallow and deep testing.

5.6.1 Sulfur deficiency symptoms

The youngest leaves of S-deficient plants are pale green and then pale yellow across the whole leaf (no striping). Under severe deficiency the entire plant becomes a lemon-yellow colour with red stems. [23]

S deficiency is expected to increase in oat crops in the future as more compound fertilisers containing lower S are used in oat production. Hay production, particularly on sandy soils, is expected to increase the risk of S deficiency as hay crops remove about 1.5 kg S/ha per tonne of hay.

5.7 Potassium

Potassium (K) is an important nutrient for oat production. Potassium is required for photosynthesis, transport of sugars, enzyme activation and controlling water balance within plant cells. Deficiency of K results in poor root growth, restricted leaf development, fewer grains per head and smaller grain size, which affects yield and quality.

K is a major nutrient that is increasingly required as soil reserves become depleted. K deficiency results in poor water use and nutrient uptake, making crops more susceptible to drought, waterlogging, frost and leaf diseases.

K deficiency can reduce the tolerance of plants to environmental stresses such as drought, frost and waterlogging, as well as pests and diseases. K deficiency can reduce straw or stalk length, leading to lodging problems. [24]

K is not as big an issue in the north as it is in the west, the exception being in central Queensland or where large amounts of hay are being removed from a paddock.

Potassium deficiency: what to look for

Paddock

- K deficiency will result in smaller lighter green plants with bronze and necrotic leaf ends, generally on sandier parts of the paddock or between header or swathe rows.
- Affected areas are more susceptible to leaf disease.

Plant

- Plants appear smaller and paler but tillering may not be affected.
- Plants may look unusually water-stressed, despite adequate water and cool conditions.
- Older leaves are affected first with dark-yellow chlorosis then necrosis that moves down from the leaf tip and edges.
- Another early symptom is development of bronze-yellow areas in the mid-section of the leaf that quickly spread to the leaf tip. Grey-brown spots develop and cause the leaf to bend at that point.
- Typically, the deficient plant develops a three-tone appearance with green younger leaves, green with yellow to bronze colours on the middle leaves and brown dead older leaves. [25]

23 DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

24 DAFWA (2016) Diagnosing potassium deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-oats

25 DAFWA (2016) Diagnosing potassium deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-oats

Table 4: What else could it be [26]

Condition	Similarities	Differences
Nitrogen deficiency	Pale plants with oldest leaves most affected	Plants and leaves more uniformly pale
Root lesion nematode	Same foliar symptoms	'Spaghetti' roots

5.7.1 Potassium and hay

Hay crops remove greater amounts of K (about 10kg K/t) compared to K in grain. The removal of nutrients in hay has to be considered when planning fertiliser requirements for following crops. [27]

Three years of trials in Western Australia in the late 1990s tested for yield response in oats for export hay, suggesting it was profitable to add K when the soil test levels were lower than 80 ppm. The addition of K did reduce some of the adverse quality effects resulting from high nitrogen rates. [28]

The trials showed that both N and K are important to optimise yield and quality of oat hay and grain. When soil test K levels are low (Colwell K soil test of less than 80 mg/kg) the response of oat plants to fertiliser N can be affected by K deficiency. To optimise the response to fertiliser N, adequate K fertliser has to be applied.

Results suggested that both oat hay and grain yields were governed mainly by applied N but required at least 70 kg K/ha to achieve their optimum levels.

While N and K interact to influence hay yield, they do not interact to influence hay quality. On K deficient soils, increasing K (regardless of N supply) reduces non-digestible fibre (NDF) and crude protein, and increases water-soluble carbohydrates (WSC) in the hay.

Grain yield increases as combined N and K fertiliser rates increase. The relationship suggests that it would not be economical to add K without an adequate amount of N fertiliser.

As with grain yield, N and K can also interact to influence grain quality. Grain quality is also affected by combined N and K fertlisers. Under low N supply, there is little benefit of K but, with high N supply, a lack of K can affect quality. [29]

More information

DAFWA Diagnosing potassium deficiency in oats

DAFWA Fertilisers and plant nutrition

GRDC Potassium and Hay

DAFWA Potassium and N Interactions

5.8 Micronutrients

5.8.1 Zinc

Zinc (Zn) is one of the 16 essential nutrients that plants need for growth and reproduction. Zinc is a micronutrient and is required in smaller amounts than some other nutrients, but it is essential. If Zn is limiting or in short supply, crop yields will suffer and crop utilisation of water and nutrients will decrease. Grain Zn content is related to seedling vigour and there is also an important link to human health, with grains being a major source of dietary zinc for many in the world. [30] Zinc is a component of many plant

[26] DAFWA (2016) Diagnosing potassium deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-oats

[27] DAFWA (2015) Oats: fertilisers and plant nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition?page=0%2C2

[28] GRDC (2001) Oaten hay big export commodity. Ground Cover Issue 35 SA, 1 January 2001, http://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-35-SA/Oaten-hay-big-export-commodity

[29] DAFWA (2015) Oats: fertilisers and plant nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

[30] R Norton (2014) What's new with zinc; maybe just some critical reminders. GRDC Update Papers, 11 February 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Whats-new-with-zinc-maybe-just-some-critical-reminders

enzymes and essential for healthy plant growth and leaf formation. [31] Zn stimulates root systems so healthy levels can assist in fighting diseases such as rhizoctonia.

Low Zn levels are commonplace in the northern region, in particular on the alkaline, self-mulching vertisols atypical of much of the region. As for all cereals, oats are highly susceptible to deficient levels of Zn in the soil.

Zinc deficiency symptoms

Zn deficiency causes patchy growth, with plants in poor areas stunted with pale-green leaves and yellow or orange-red tips. Youngest leaves usually remain green; middle and older leaves turn pale green and pale-yellow areas develop between the leaf edge and mid-vein at the tip. Brown spots occur in the affected areas, increasing in size until the leaf tip dies, often turning red-brown to black.

With severe deficiency the stem remains very short and the youngest leaves have difficulty emerging fully. The symptoms can be mistaken for that of barley yellow dwarf virus or severe P deficiency.

If group B herbicides have been used, Zn strategy may need to be revisited. Some group Bs can lower levels of Zn uptake in the plant. [32]

Zn deficiencies tend to occur early in the growing season, when the soils are cold and wet. This is due to slow root growth compared with rapid shoot growth. The slow-growing root system is unable to take up enough Zn to supply the shoot. Plants sometimes appear to outgrow this deficiency, but the damage has already been done and yields can still be significantly reduced. Root-pruning herbicides such as SUs can give a similar response. [33]

Addressing zinc deficiency

If the indicators used suggest Zn response is likely, several options are available. Irrespective of the strategy, a couple of important aspects of using supplementary Zn need to be considered.

Roots move to Zn and, therefore, the distribution of drilled Zn needs to be even. Banding with a product that has a reliable particle size and Zn content is important. Soil mixing (e.g. via cultivation) can dilute Zn concentration and, if placed too shallow, the Zn can be ‘stranded’ in dry soil if the season is slow to take up.

Crops differ in their response to zinc so, within a rotation, it is more important to apply Zn ahead of or onto responsive crops. In general, canola is relatively more efficient than cereals at accessing soil Zn (Brennan and Bolland 2002), while lupins, faba beans and chickpeas have lower demands than wheat, and lentils have a higher demand (Brennan et al. 2001). Maize and sorghum have higher Zn demands than wheat or barley. So, in a crop rotation, address the Zn demand in the cereal phase rather than the pulse or oilseed phase.

While foliar Zn can be used for rescue operations, it has little residual value. In comparison, soil-applied Zn (with macronutrient) has a residual value of 2–5 crops, depending on soil texture and pH. [34]

31 DAFWA (2015) Oats: Fertilisers and nutrition https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

32 GRDC (2013) Micronutrients. Nothern, Southern and Western Regions, GRDC Crop Nutrition Fact Sheet, November 2013, https://www.grdc.com.au/~/media/Documents/Resources/Publications/Fact-sheets/GRDC_FS_Micronutrients_low-res-pdf.pdf

33 R Norton (2014) What’s new with zinc; maybe just some critical reminders. GRDC Update Papers, 11 February 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Whats-new-with-zinc-maybe-just-some-critical-reminders

34 R Norton (2014) What’s new with zinc; maybe just some critical reminders. GRDC Update Papers, 11 February 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Whats-new-with-zinc-maybe-just-some-critical-reminders

Table 5: *What else could it be*

Condition	Similarities	Differences
Yellow dwarf virus	Red or yellow leaf colours and necrosis that starts at the tip	Necrotic areas lack red-brown lesions; the disorder tends to be circular or near the edge of the paddock and not associated with soil type

5.8.2 Copper

Oats are less susceptible to copper (Cu) deficiency compared with wheat and barley; however, Cu is essential for growth and development. Plants need Cu to produce new cells and for pollen development (sterile pollen), and hence Cu deficiency severely effects grain yield. [35] Cu is essential for chlorophyll formation and pollen production as well as baking quality. [36]

Copper deficiency

Deficient plants that apparently look healthy can produce shrivelled grain, reducing both grain yield and quality.

Cu-deficient crops have a patchy appearance, with plants in poor areas stunted, pale green and looking limp and wilted, even with ample soil water. Late tillers may develop at nodes or joints above ground. Young leaves turn pale green while old leaves remain green. Under conditions of severe deficiency, some leaves may die back from the tip and twist into curls.

The ears of Cu-deficient plants are shrunken, with gaps such as 'frosted heads'. The heads of Cu-deficient plants have poor seed-set from sterile pollen, thus resulting in 'white heads', similar to the ear heads affected by drought, heat stress or frost. [37]

Crops deficient in K or Cu may have increased susceptibility to frost events. This can be assessed with plant tissue testing at tillering.

Applying 3–9 kg/ha of copper sulfate (25% Cu) with fertiliser at seeding in areas suspected to be deficient in Cu should correct the deficiency. Copper fertiliser is long residual in the soil, and a single Cu application at recommended rates can last 20–30 years.

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. [38]

Cu deficiency occurs on organic soils, and on sandy, low organic-matter soils deficiency is common, as well as where there is high Iron (Fe), manganese (Mn) or aluminium (Al) in the soil. [39]

Copper deficiency: what to look for

Paddock

- Before head emergence, deficiency shows as areas of pale, wilted plants with dying new leaves in an otherwise green healthy crop.

[35] DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

[36] R Norton (2014) Trace elements: copper and manganese – their role, requirements and options. GRDC Update Paper, 20 August 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Trace-elements-copper-and-manganese-their-role-requirements-and-options

[37] DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

[38] DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

[39] R Norton (2014) Trace elements: copper and manganese – their role, requirements and options. GRDC Update Paper, 20 August 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Trace-elements-copper-and-manganese-their-role-requirements-and-options

- After head emergence, few grains are set and plants become discoloured and mature later.
- Symptoms are often worse on sandy or gravelly soils, where root-pruning herbicides have been applied and in recently limed paddocks.

Plant

- Youngest growth is affected first.
- Young leaves turn pale green and wilted, then die back from the tip. Dead tissue usually rolls or twists into a tight tube or spiral.
- Old leaves remain green, but paler than normal.
- Tiller production before flowering is often unaffected but they may die prematurely. After flowering, very late tillers often appear. [40] Normal cereal heads can be replaced with 'rat-tail' heads.

More information

DAFWA Copper

Table 6: What else could it be [41]

Condition	Similarities	Differences
Stem and head frost damage	Aborted seed	Rarely affects the whole panicle; plants are not discoloured or produce late tillers

5.8.3 Manganese

Manganese (Mn) is a common coenzyme cofactor for chlorophyll and photosynthesis.

Mn deficiency is mainly a problem on high-organic-matter soils, and those with free lime present or on recently limed soils. It may be toxic at low pH (<5).

Oats are very susceptible to Mn deficiency, which produces a condition called 'grey speck'. Oats are generally as sensitive as wheat, canola, peas and beans to low Mn levels. [42]

Manganese deficiency: what to look for

Paddock

- Mn deficiency often appears as patches of pale, floppy plants in an otherwise green, healthy crop.

Plant

- Middle leaves are affected first, but it can be difficult to determine which leaves are most affected as symptoms rapidly spread to other leaves and the growing point.
- Plants become pale green. Small, linear grey flecks appear on interveinal tissue in the basal half of old leaves, extending towards the tip as symptoms develop.
- Flecks often join to form large lesions in the basal half of the leaf between the margin and mid-vein, eventually affecting the vein. Leaves often kink, collapse and eventually die, giving plants a wilted appearance.
- Tillering is reduced, with extensive leaf and tiller death. With extended deficiency, the plant may die.
- Surviving plants produce fewer and smaller heads.

40 DAFWA (2015) Diagnosing copper deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-oats

41 DAFWA (2015) Diagnosing copper deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-copper-deficiency-oats

42 R Norton (2014) Trace elements: copper and manganese – their role, requirements and options. GRDC Update Paper, 20 August 2014, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Trace-elements-copper-and-manganese-their-role-requirements-and-options

Table 7: What else could it be [43]

Condition	Similarities	Differences
Nitrogen deficiency	Pale plants	Do not show wilting, interveinal chlorosis or leaf kinking and do not die
Waterlogging and salinity	Pale plants	Do not show wilting, interveinal chlorosis or leaf kinking and do not die
Iron deficiency	Pale plants	New leaves are affected first and plants do not die
Sulfur deficiency	Pale plants	New leaves are affected first and plants do not die

Tissue tests and visual symptoms can be used to help diagnose Mn deficiency. Mn concentrations less than 20 ppm (mg/kg) in whole shoots indicate Mn deficiency. The concentrations of Mn in tissues vary for different oat varieties.

Applying manganese sulphate (25% Mn) as a foliar spray at a rate of 4 kg/ha (1 kg Mn/ha in 50–100 L of water) immediately symptoms appear is usually effective in correcting a Mn deficiency; however, a repeat spray a few weeks later may be necessary. [44]

5.8.4 Boron

Boron (B) is essential for germination and sugar metabolism.

Lucerne is more susceptible to deficiency than canola, and wheat is less susceptible than canola.

Symptoms of deficiency include stem-splitting and poor seed-set.

Liming can induce B deficiency.

Critical tissue levels are <2 mg/kg in the youngest mature leaf blade at mid–late tillering. Leaching can reduce tissue levels.

B sources are borax, boric acid, Solubor®, ulexite and sodium pentaborate. Even application is critical.

5.8.5 Iron

Iron (Fe) is an essential component of chlorophyll and in respiratory enzymes.

Legumes are more responsive to iron than are cereals.

Chlorosis of the youngest part of the plant is the most common symptom of deficiency.

Deficiency is worst in high pH and low-organic-matter soils, especially if there is a lot of free bicarbonate (soil or irrigation water origin).

Soil analysis is not able to provide critical values, and tissue samples can be easily contaminated with Fe from soil. Levels of 70 mg/kg or more in tissue seem adequate.

Foliar sprays are useful as iron sulfate or side dressings with iron chelates. [45]

5.9 Nutrition effects on following crop

Oats, like other cereals, have a high demand for nitrogen (N), no matter what the use of the oat crop—grazing, grain or hay or silage production. Shallow and deep tests should be undertaken in the summer following the oat crop to determine the total N available to the following crop and an appropriate N budget developed on this basis.

If hay or silage was produced off the paddock, K levels could be of concern, and soils tested to ascertain starting K levels.

43 DAFWA (2016) Diagnosing manganese deficiency in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-manganese-deficiency-oats

44 DAFWA (2015) Oats: Fertilisers and nutrition, https://www.agric.wa.gov.au/oats/oats-fertilisers-and-plant-nutrition

45 R Norton, J Laycock, C Walker (2012) Trace elements—importance. GRDC Update Papers 14 Feb. 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/02/Trace-Elements-Importance

5.10 Salinity, acidity and sodicity

5.10.1 Salinity

Oats are moderately tolerant to salt, but not as tolerant as barley is.

Salinity, predominantly caused by excess sodium chloride (NaCl) in the soil, is a serious problem throughout Australia, restricting agricultural productivity and degrading the natural environment.

Salinity is the total concentration of water-soluble salts in water and soil. Soil salinity can be measured as a concentration, but in most agricultural situations it is measured as the electrical conductivity of a saturated soil paste (ECe) or a 1:5 (EC1:5) water extract in units of deci Siemens per metre (dS/m) at 25°C.

Salinity can affect plants in three ways.

Initially, salt makes it more difficult for plants to withdraw water from the soil, even if the soil appears quite moist. In effect, the plant suffers from a form of drought, which can result in retarded growth and reduced yield.

Second, some salts, such as Na and Cl can be directly toxic to plants. Plants take up salts with the water that they use, and often these salts can damage the plant internally, affecting the plant's physiological processes and often resulting in reduced growth, leaf burn and even plant death. This effect is the most serious for plants.

Third, high amounts of ions such as Na and Cl may affect the availability of other ions such as K, Mg, N or P, which are extremely important for plant growth. [46]

Salinity symptoms: what to look for

Paddock

- Salinity will produce poor germination or pale plants in water-collecting areas, particularly on shallow duplex soils.
- Wet soil and/or water-loving weeds or salt-tolerant plants will be evident as salinity increases.
- N-deficient plants with more leaf necrosis and premature death will be evident in more saline areas.

Plant

- Plants have a harsh droughted appearance, and may be smaller with smaller dull leaves.
- Old leaves develop dull-yellow tips and die back from the tips and edge.
- Premature death will occur. [47]

Table 8: What else could it be [48]

Condition	Similarities	Differences
Nitrogen deficiency	Similar foliar symptoms	No root browning and less old leaf necrosis and symptoms are not confined to wet or saline areas

[46] Agriculture Victoria (1997) Salinity and the growth of forage species, http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/salinity/salinity-and-the-growth-of-forage-species

[47] DAFWA (2015) Diagnosing waterlogging and salinity in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-and-salinity-oats

[48] DAFWA (2015) Diagnosing waterlogging and salinity in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-and-salinity-oats

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

5.10.2 Acidity

Soil acidification is a natural process in which the soil pH decreases over time. Many of our farming practices increase the rate of acidification. Soils with a light texture (in other words, a high sand content) and low organic matter content are most susceptible to acidification, particularly if high levels of nitrogen fertilisers are applied.

The symptoms of soil acidity include:

- uneven pasture growth
- poor nodulation of legumes
- stunted root growth and high incidence of root diseases
- invasion of acid-tolerant weeds (e.g. fog grass, sorrel, geranium)
- difficulty establishing lucerne, phalaris and medics
- formation of organic mats on the ground surface due to reduced biological activity

Problems that can occur in acid soils include:

- Al and Mn toxicity in plants
- decreased availability of N, P, K, S, Mo, Mg, B and Ca to plants
- decreased biological activity of soil microbes and thus reduced recycling of nutrients
- suppression of rhizobia bacteria, which affects legume nodulation
- suppression of root growth and the plant's ability to take up water and nutrients.

Soil acidity is corrected by applying agricultural lime (calcium carbonate) or dolomite [49]

5.10.3 Sodicity

Sodicity, simply defined, is the presence of too much sodium (Na) in the soil. [50]

Sodic soils are prone to poor soil structure, particularly if the natural equilibrium between salinity and sodicity are out of balance. Both acidic–sodic and alkaline–sodic soils occur within the northern grains zone, often within the one soil profile. Sodic soils often disperse more after mechanical disturbance (e.g. compaction, tillage) and erosion. Gypsum application to these soils improves the soil structure, facilitating leaching of salts, even under dry land conditions (Rengasamy 2010). Correcting cation imbalances requires providing a source of the 'good' cations, Ca2+ and/or Mg2+, which might come from gypsum, lime or dolomite applications. The choice will depend on considerations such as cost, the existing cation balance in the soil and the speed at which a change is required. The application of gypsum will generally give quicker results as it has a relatively high solubility, whereas agricultural lime has a very low solubility and therefore takes longer for observable results. It is also dependent on the pH of the soil. [51]

More information

GRDC Profit Suckers – Understanding salinity sodicity and deep drainage

GRDC Soil sodicity chemistry physics and amelioration

49 Agriculture Victoria (2015) Managing factors that can limit plant growth. http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/fertilising-dairy-pastures/managing-factors-that-can-limit-plant-growth

50 Agriculture Victoria (2015) Managing factors that can limit plant growth. https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Soil-Sodicity-chemistry-physics-and-amelioration

51 Agriculture Victoria (2015) Managing factors that can limit plant growth. https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Profit-suckers-understanding-salinity-sodicity-and-deep-drainage

SECTION 6

Weed control

More information

https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/oats/diseases-and-weeds

https://www.agric.wa.gov.au/oats/oats-weeds-and-integrated-weed-management

NSW DPI: Weed Control in Winter Crops 2015

Oats compete better than barley, wheat, canola and pulses when sown at recommended seeding rates because of its greater tillering ability. If given the right start, an oat crop has the necessary vigour to compete against weeds. Increasing crop density may improve competitiveness and ultimately impact on yield. [1]

Caution is needed when spraying oats, as it has a much lower tolerance of 2,4-D and MCPA sprays than the other cereals. [2] Chemical control should be timely with respect to both weed size and development of the crop.

Weeds cost Australian agriculture an estimated AU$2.5–4.5 billion per annum. For winter cropping systems alone, the cost is $1.3 billion, equivalent to ~20% of the gross value of the Australian wheat crop. Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry. [3]

Fallow weed control is essential if oats is to make full use of summer rainfall, and in order to prevent weed seeds from contaminating the grain sample at harvest. Weed management should be planned well before planting and options considered such as chemical and non-chemical control. [4]

Weed control is important, because weeds:

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

More information

GRDC: Weed Webinars

GRDC: Weed ID. The Ute Guide

NHT: Introductory weed management manual

1 DAFWA (2015) Oats: weeds and integrated weed management. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-weeds-and-integrated-weed-management

2 https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/oats/diseases-and-weeds

3 GRDC (2014) Integrated weed management hub. GRDC, www.grdc.com.au/weedlinks

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

More information

[NSW DPI: WeedWise]

[Sydney Royal Botanic Gardens Herbarium: PlantNET]

[WA Herbarium: FloraBase]

[WEEDpak Weed ID guide]

[Weeds Australia: Weed identification tool]

6.1 Fallow weed control

6.1.1 Water use efficiency

The greatest scope for many producers in the Northern region to increase WUE (and profitability) is weed control in the fallow phase. Quite often the fallow phase and the cropping phase are looked upon as being two separate components requiring completely different strategies. However, these need to be looked at in less isolation, and instead maximise the potential synergies that exist between the two.

The water used by weeds between crop maturity and the first fallow spray should not be underestimated. The first point of control with many weeds is not knowing which herbicide kills it, but knowing its life cycle.

6.1.2 The effect of grazing on crop residues

A report by Bell et al. (2011) says that while there may be small effects of stock on surface compaction and infiltration rates on many soil types, there generally appears to be little effect on subsequent crop yield. However there are two main reasons why the grazing of summer fallows may lead to yield loss in a farm situation.

The first reason is that often the grazing of crop residues results in poor fallow weed control and subsequent lower levels of stored water for the following crop.

The second reason is that livestock may remove crop residues, resulting in increased evaporation rates following rainfall events which may in turn reduce sowing opportunities in autumn. [5]

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/431277/Optimising-water-use-efficiency-in-western-NSW.pdf

6.1.3 The effect of summer weeds on nitrogen

In addition to depleting soil water, large amounts of nitrogen are tied up and are unavailable to the next crop due to weeds growing in the fallow. Also, by killing weeds and storing more soil water, modest increases in the levels of soil water will increase the amount of soil nitrate mineralised in the fallow period – further increasing nutrient availability to the next crop (Table 8).

Key points:

- The higher levels of soil water in fallows where weeds are controlled are likely to see more nitrogen mineralised in the fallow period that will be available for use by the following crop.
- Extra nitrogen available to a crop through fallow weed control is reflected in both yield and potentially also in grain protein, and
- Every 1 mm of moisture lost via summer weed growth also reduced mineral nitrogen levels by approx 0.64 kgN/ha (McMaster, 2013). [6]

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5 R Brill. Optimising water use efficiency in western NSW. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/431277/Optimising-water-use-efficiency-in-western-NSW.pdf

6 http://www.grdc.com.au/~/media/Documents/Resources/Publications/Summer-fallow-weed-management-manual.pdf?la=en

Table 1: Changes in soil nitrogen and water status

	Wet - irrigated			Dry – rain fed		
	+ Weeds	No weeds	Difference	+ Weeds	No weeds	Difference
Change in plant avail N in top 300 mm (kg/ha)	-11	+13	24	+10	+17	7
Total water loss during summer fallow (mm)	-212	-120	92	-66	-58	8

http://www.grdc.com.au/~/media/Documents/Resources/Publications/Summer-fallow-weed-management-manual.pdf?la=en

Green bridge

Several diseases and insects that damage crops are vectored on weeds in the summer fallow. These include: cereal rusts, wheat streak mosaic virus, crown rot, barley yellow dwarf virus, beet western yellow virus, bean leaf roll virus, diamondback moth, mites and Rhizoctonia.

The ideal situation is to have a long period of no green bridge during the summer period. The critical period is the four to six weeks prior to sowing. All weeds and crop volunteers should be killed before and during this window. [7]

http://www.grdc.com.au/~/media/Documents/Resources/Publications/Summer-fallow-weed-management-manual.pdf?la=en

6.2 Herbicides

6.2.1 Pre-emergent herbicides

There are few pre-emergent herbicide options for oats as most of these chemicals are targeted at controlling wild or black oats and will subsequently kill white oats. As such, paddock selection of a grass weed-free paddock for oats is imperative to ensure both maximum yield or DM production from the crop and to ensure weed seed numbers are minimized for the following year

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/123157/weed-control-in-winter-crops-2015.pdf

6.2.2 Post-plant pre-emergent herbicides

Few products are registered in this space for oats. Diuron, however, is registered for suppression of annual ryegrass, barley grass and silver grass in a post-plant, pre-emergent situation.

http://www.bcg.org.au/members/download_trial.php?trial_id=398

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/123157/weed-control-in-winter-crops-2015.pdf

Australian Pesticides and Veterinary Medicines Authority

6.2.3 In-crop herbicides: knock downs and residuals

Please refer to the NSW DPI's Weed Control in Winter Crops and the APVMA website.

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/123157/weed-control-in-winter-crops-2015.pdf Page 5

https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/oats/diseases-and-weeds

Australian Pesticides and Veterinary Medicines Authority

7 http://www.grdc.com.au/~/media/Documents/Resources/Publications/Summer-fallow-weed-management-manual.pdf?la=en

6.2.4 Potential herbicide damage effect

When researching the residual activity and cropping restrictions following herbicide application, the herbicide label is the primary source of information and it should be read thoroughly. The information below provides an explanation of how herbicides break down and extra notes on some specific herbicides used in broadacre cropping.

Figure 1: Paraquat damage in a young oat crop.(Photo. David Pfeiffer)

What are the issues?

Some herbicides can remain active in the soil for weeks, months or years. This can be an advantage, in that it ensures good long-term weed control. However, if the herbicide stays in the soil longer than intended, it may damage sensitive crop or pasture species sown in subsequent years.

For example, chlorsulfuron (Glean®) is used in oats, but it can remain active in the soil for several years and damage legumes and oilseeds, especially in dry seasons or on certain soil types, such as high pH soils

A real difficulty for growers lies in identifying herbicide residues before they cause a problem. We rely on information provided on the labels for soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if testing is possible, it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease. [8]

The problem with crop residues is that the following susceptible crop may take some time to tap into the chemical band. The crop can germinate and appear to have 'normal' growth but then weeks and sometimes months into the growing season can hit the band and suffer damage or even death. By this stage the crop may have received considerable and costly inputs and the re-planting window to a more tolerant crop may have closed

8 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. DEDJTR Victoria, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

An option for assessing the potential risk of herbicide residues is to conduct a bioassay involving hand-planting small test areas of crop into the field in question.

Figure 2: Oats with damage from Sakura residues in the spray tank. (Photo. Rural Directions)

Which herbicides are residual?

The herbicides listed in Table 2 all have some residual activity or planting restrictions.

Table 2: Active constituent by herbicide group (may not include all current herbicides)

Herbicide group	Active constituent
Group B. Sulfonylureas	Chlorsulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)
Group B. Imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)
Group B. Triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)
Group C. Triazines	Atrazine, simazine
Group C. Triazinones	Metribuzin (Sencor®)
Group C. Ureas	Diuron
Group D. Dinitroanilines	Pendimethalin (Stomp®), trifluralin
Group H. Pyrazoles	Pyrasulfotole (Precept®)
Group H. Isoxazoles	Isoxaflutole (Balance®)
Group I. Phenoxy carboxylic acids	2,4-Ds
Group I. Benzoic acids	Dicamba
Group I. Pyridine carboxylic acids	Clopyralid (Lontrel®)
Group K. Chloroacetamides	Metolachlor
Group K. Isoxazoline	Pyroxasulfone (Sakura®)

How do herbicides break down?

Herbicides break down via chemical or microbial degradation. The speed of chemical degradation depends on the soil type (clay or sand, acid or alkaline), moisture and temperature. Microbial degradation depends on a population of suitable microbes living in the soil to consume the herbicide as a food source. Both processes are enhanced by heat and moisture. However, these processes are impeded by herbicide binding to the soil, and this depends on the soil properties (pH, clay or sand, and other compounds such as organic matter or iron).

For these reasons, degradation of each herbicide needs to be considered separately and growers need to understand the soil type and climate when trying to interpret re-cropping periods on the product label for each paddock. [9]

How can I avoid damage from residual herbicides?

Select an appropriate herbicide for the weeds and their growth stage taking into account if resistant weeds could be amongst the population

Have a fixed crop rotational plan 2- 5 years ahead, this should also include your herbicide rotation to avoid chemical residues and as a sound tool for herbicide resistance management. Make sure you consider what the re-cropping limitations may do to future rotation options.

Users of chemicals are required by law to keep good records, including weather conditions, but particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock). 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. [10]

Group B. Sulfonylureas, Triazolopyrimidines (sulfonamides) and Imidazolinones

The sulfonylureas persist longer in alkaline soils (pH >7), where they rely on microbial degradation.

Residual life within the sulfonylurea family varies widely, with chlorsulfuron (Glean®) persisting for ≥2 years, depending on rate, and not suitable for highly alkaline soils. Triasulfuron (Logran®) persists for 1–2 years and metsulfuron (Ally®) generally persists for <1 year.

Legumes and oilseeds, particularly lentils and medic, are most vulnerable to sulfonylureas. However, oats can also be more sensitive sulfonylureas than other cereals—check the label.

Debate remains about the ideal conditions for degradation of Triazolopyrimidines (sulfonamides) herbicides which include Crusader ® and Eclipse®. However, research in the alkaline soils of the Victorian Wimmera and Mallee, and the Eyre Peninsula in South Australia, has shown that the sulfonamides are less likely to persist than the sulfonylureas in alkaline soils. Plant-back periods should be increased in shallow soils.

The imidazolinones are very different from the sulfonylureas; the main driver of persistence is soil type, not soil pH. They tend to be more of a problem on acid soils, but carryover does occur on alkaline soils. Research has shown that in sandy soils, such as on the Eyre Peninsula, they can break down very rapidly (within 15 months in alkaline soils), but in heavy clay soils in Victoria they can persist for several years. Breakdown is by soil microbes. Oilseeds are most at risk. Widespread use of imidazolinone-tolerant canola and wheat in recent years has increased the incidence of imidazolinone residues. Longer residues exist for oats than for other cereal crops. An

[9] Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. DEDJTR Victoria, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

[10] Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, DEDJTR Victoria, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

example being for Spinnaker®, the plantback to non-Clearfield wheat and barley is 11 months provided greater than 300 mm has fallen in the fallow period. For oats the re-cropping interval is 22 months

Group C. e.g Triazines

Usage of triazines has increased to counter Group A resistance in ryegrass, in particular in triazine-tolerant canola. Atrazine persists longer in soil than simazine. Both generally persist longer on high pH soils, and cereals are particularly susceptible to damage. Research in the US indicates that breakdown rates tend to increase when triazines are used regularly, because the number of microbes able to degrade the herbicide can increase. This may mean that breakdown can take an unexpectedly long time in soils that have not been exposed to triazines for some years. Many triazines are registered for the control or suppression of wild oats and as such would be very damaging to cereal sown oats

Figure 3: Simazine damage in oats. (Photo Tony Cook)

Group D. dinitroanilines

Trifluralin tends not to leach through the soil, but it can be moved into the seedbed during cultivation or ridging. Trifluralin binds strongly to stubble and organic matter and is more likely to be a problem in paddocks with stubble retention. Be particularly careful with wheat, and lentils. Barley is more tolerant. Trifluralin is not registered in oats but is registered for control of both wild oats and cereal oats

Group H. Isoxazoles

Persistence in acid soils (pH <7) has not been fully tested, but research shows that isoxazoles, such as Balance®, persistence is expected to be longer than the label recommendations for legume crops and pastures. Isoxazoles will also persist longer in clay soils and those with low organic matter.

Group I. Phenoxies and pyridines

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

2,4-D used for fallow weed control in late summer may cause a problem with autumn-sown crops if plant-back periods are not observed. Changes have been made to the 2,4-D label recently and not all products can be used for fallow weed control—check the label.

The label recommends that you not sow sensitive crops, especially canola, until after a significant rainfall event. Oilseeds and legumes are very susceptible to injury from 2,4-D.

Oats are less tolerant of Group I products that wheat and barley. Oats is not registered on as many of the phenoxy's as wheat and barley e.g Estercide Xtra 680. The maximum in-crop rates can be less than that for the other cereals e.g.Amicide and the plant back periods are generally longer than wheat and barley

Group K. Chloroacetamides and isoxazolines

Metolachlor, a component of Boxer® Gold and pyroxasulfone (Sakura®), would be the two most common Group K chemicals used in winter cropping. Both of which are effective in controlling wild oats and would consequently kill cereal oats if applied to a crop

Pyroxasulfone (Sakura®), relies on microbial degradation, which is favoured by in-season rainfall. Label plant-back periods are important particularly for oats, durum wheat and canola. Residues will lead to crop stunting. [11]

Figure 4: Oats with damage from Sakura residues in the spray tank. (Photo. Rural Directions)

More information

[Australian Pesticides and Veterinary Medicines Authority]

6.3 Integrated weed management (IWM)

Weed competition can be affected by crop species, crop variety, weed species, crop and weed density and time of emergence of the crop relative to the weed.

Oats are more competitive with weeds than barley, wheat, canola and pulses when sown at recommended seeding rates because of its greater tillering ability. If given the right start, an oat crop has the necessary vigour to compete against weeds. Increasing crop density may improve competitiveness and ultimately impact on yield.

Cutting hay is a common method used for reducing the weed seed bank, as it removes any weeds that have survived the in-crop spray-. Effective weed management in-season for hay crops is also essential as weed contamination is directly related to quality of

[11] Agriculture Victoria (2013) Avoiding crop damage from residual herbicides, DEDJTR Victoria, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

the end product. Weed seeds in a sample may prevent the hay making export grade, decrease it’s feed value or may contain weeds that are toxic to stock

Preventing weeds from entering or establishing in a paddock is the best method of weed management, especially when combined with physical, agronomic and chemical options. Some of the non-chemical options available in IWM are:

- use of weed-free seed
- clean machinery when moving between paddocks and on farms
- tarp loads when moving grain
- control weeds along roadsides at the edge of paddocks
- eradicate small patches of new invading weeds
- consider weeds when importing hay
- don’t import grain or products that may contain certain herbicide resistant weed seeds
- crop and pasture rotations using species with different competitive abilities, sowing dates and harvesting techniques such as swathing
- increase seeding rates and reduce row spacings to maximise crop-weed competition and yield without reducing grain size
- sow cereals in an east-west direction
- implement a tickle cultivation to stimulate germination of ryegrass and other weeds prior to seeding or grazing with sheep or cattle [12]

6.3.1 Reducing glyphosate resistance

Glyphosate is a key herbicide in Australia’s farming system and responsible use is required to prolong its effective life.

IWM should be applied by growers to sustain glyphosate and reduce the incidence of resistance in weeds, particularly ryegrass.

A double knockdown technique will minimise the risk of resistance developing. Double knockdown is the sequential use of glyphosate followed by a mixture of paraquat + diquat.

Best practices for double knockdown include:

- Glyphosate followed by paraquat or a diquat/paraquat mix such as Sprayseed®.
- Spraying the first herbicide at the 3-6 leaf stage of ryegrass results in the best control
- The interval between knockdowns needs to be at least 1 day when using the glyphosate followed by paraquat +diquat but a 2-10 day interval is more effective if seasonal conditions permit
- Allowing a longer interval before the second spray will ensure plants emerging after the first knockdown are killed. [13]

6.3.2 Protecting herbicides

Rapid expansion of herbicide resistance and the lack of new modes of action (MOA) require that non-herbicide tactics must be a significant component of any farming system and weed management strategy.

Inclusion of non-herbicide tactics is critical to prolong the effective life of remaining herbicides, as well as for new products and MOA.

12 DAFWA (2015) Oats: weeds and integrated weed management. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-weeds-and-integrated-weed-management

13 DAFWA (2015) Oats: weeds and integrated weed management. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-weeds-and-integrated-weed-management

Effective herbicides are key components of profitable cropping systems. Protecting their efficacy directly contributes to the future sustainability and profitability of cropping systems.

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

Successful weed management requires a paddock-by-paddock approach. Weeds present and weed-bank status, soil types in relation to to herbicide used, and cropping and pasture plans need to be captured in both a paddock audit and a rotational plan going forward a number of years for that paddock. Knowledge of paddock history and of how much the summer and winter weeds have been selected for resistance (and to which herbicide MOAs) can also assist.

When resistance has been identified, knowledge of which herbicides still work becomes critical.

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

1. Review past actions and history.
2. Assess current weed status.
3. Identify weed-management opportunities.
4. Match opportunities and weeds with suitably effective management tactics.
5. Combine ideas into a management plan. Use of a rotational plan can assist. [14]

6.3.3 Review past actions

The historical level of selection pressure can be valuable information for managers to gauge which weed–MOA groups are at greatest risk of breaking. Such knowledge can prompt more intensive monitoring for weed escapes when a situation of higher risk exists. Picking up newly developing resistance issues while patches are still small and before they spread can mean a big difference in the cost of management over time.

From all available paddock records, calculate or estimate the number of years in which different herbicide MOAs have been used. The number of years in which a herbicide MOA has been used is of far greater relevance than the number of applications in total. For most weeds, use of a herbicide MOA in two consecutive years presents a far greater selection pressure for resistance than two applications of the same herbicide MOA in the one year. If the entire paddock history is unavailable to you, state what is known and estimate the rest. Collate separate data on MOA use for summer and winter weed spectrums. Further subdivide these into broadleaf and grass weeds.

Account for double-knocks. Where survivors of one tactic would have been largely controlled by the use of another tactic, reduce the number of MOA uses accordingly. An example might be as follows. Trifluralin (Group D) has been used 20 times, but there were 6 years when in-crop Group A selectives were used and several more years when in-crop Group B products (targeting the same weed as the trifluralin) were used. These in-crop herbicides effectively double-knocked the trifluralin, thus reducing the effective selection pressure for resistance to trifluralin.

Review the data you have collected and identify which weed–MOA groups have been selected for at a frequency likely to lead to resistance in the absence of a double-knock. Trifluralin typically takes about 10–15 years of selection for resistance to occur (Table 3). Thus, in the above example, a 'watching brief' would be in place for trifluralin and other Group D MOA herbicides.

[14] DAFWA (2015) Oats: weeds and integrated weed management. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-weeds-and-integrated-weed-management

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

Information on MOA use history should be added to paddock records. [15]

Table 3: Typical number of years of use of mode of action (MOA) groups before weeds develop resistance

Herbicide Group	Typical years of application	Resistance risk
A (fops/dims/dens)	6–8	High
B (sulfonylureas, imidazolinones)	4	High
C (triazines, substituted ureas)	10–15	Medium
D (trifluralin, pendimethalin)	10–15	Medium
F (diflufenican)	10	Medium
I (phenoxies)	>15	Medium
L (paraquat/diquat)	>15	Medium
M (glyphosate)	>12	Medium

6.3.4 Assess the current weed status

Record the key broadleaf and grass weed species for summer and winter and include an assessment of weed density, with notes on weed distribution across the paddock. Include GPS locations or reference to spatial location of any key weed patches or areas tested for resistance.

Include any data, observations or information relating to the known or suspected herbicide-resistance status of weeds in this paddock.

Add this information to paddock records. [16]

6.3.5 Identify weed management opportunities

Identify which different herbicide and non-herbicide tactics could be cost-effectively added to the system and at what point in the crop sequence these can be added. For further information on the different IWM tactics see: IWM Section 4: Tactics. [17]

The RIM decision-support software provides insights into the long-term management of annual ryegrass in dryland broadacre crops facing development of herbicide resistance. RIM enables alternative strategies and tactics for ryegrass management to be compared for profit over time and for impact on weed numbers. The software's underlying model integrates biological, agronomic and economic considerations in a dynamic and user-friendly framework, at paddock scale and over the short and long term.

The tool tracks the changes through time on a 10-year crop cycle for ryegrass seed germination, seed production and competition with the crop. Financial returns are also estimated annually and as a 10-year average return.

A free download is available from: http://www.ahri.uwa.edu.au/RIM. [14]

More information

NSW DPI: Weed management in winter crops

NSW DPI: Weed management in summer crops

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

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

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

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

GRDC Update Papers

Biology and management of summer weeds

Brome and barley grass management in cropping systems of southern Australia

Fleabane ecology and control in cropping systems of southern Australia

Fodder rotations with cropping to manage weeds

Hardseeded annual legumes

Herbicide efficacy in no-till farming systems in southern NSW

Herbicides for control of clethodin-resistant annual ryegrass

Hitting the right target—what are our most costly weeds?

Impact of crop residues on summer fallow weeds

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

New herbicide challenges and solutions

New technology for improved herbicide use efficiency

NGA chickpea herbicide trials 2015

Optimising the impact of glyphosate

Seeding systems and pre-emergence herbicides

Summer weeds reduce moisture and nitrogen

Using crop competition for weed control in barley and wheat

Why the obsession with the ryegrass seed bank?

6.3.6 Fine-tune your list of options

What other tools are available to you in your tool box to add to current weed management tactics to add diversity and help drive down the weed seedbank? [19]

6.3.7 Combine and test ideas

Computer simulation tools can be useful to run a number of 'what if' scenarios to investigate potential changes in management and the likely effect of weed numbers and crop yield. Two simulation tools in use are the Weed Seed Wizard and RIM.

Combine ideas using a rotational planner, or test them by using decision-support software such as RIM and Weed Seed Wizard. [20]

Weed Seed Wizard

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

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

The 'Wizard' uses farm-specific information, and users enter their own farm-management records, their paddock soil type, local weather and one or more weed species. The Wizard has numerous weed species to choose from including annual ryegrass, barley grass, wild radish, wild oat, brome grass and silver grass in the southern states, and liverseed grass, barnyard grass, paradoxa grass, feather-top Rhodes grass, bladder ketmia, fleabane, sowthistle, sweet summer grass, cowvine and bellvine in the north.

A free download is available from: https://www.agric.wa.gov.au/weed-seed-wizard-0. [17]

6.4 Agronomy

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

6.4.1 Crop choice and sequence

Many agronomic and weed management issues arise from the sequence in which crops are sown:

- Rotations provide options for different weed-management tactics.
- Crop rotations can improve crop fertility and help to manage disease and insects. Healthy crops are more competitive against weeds.

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

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

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

- Many weeds are easier or more cost-effective to control in specific crops, pastures or fallows.

The ability to compete with weeds varies between crop type and variety. In paddocks with high weed pressure, a competitive crop, such as oats, will enhance the reduction in weed seedset obtained through other weed-management tactics. It will also reduce the impact that surviving weeds have on crop yield and the quantity of seedset by any surviving weeds. [22]

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

Some key issues:

- Select crop sequences and varieties to deal with the significant pathogens and nematode issues for each paddock.
- Weeds are alternate hosts to some crop pathogens. Effective weed management can reduce disease pressure.
- *Rhizoctonia* can affect seedling crop growth, leaving the crop at greater threat from weed competition. Removing weeds for a period prior to sowing can significantly reduce the level of *Rhizoctonia* inoculum.
- Weed growth in the fallow or in-crop can increase moisture use and exacerbate yield loss from diseases such as crown rot.
- Residual herbicides used in the fallow or preceding crop may limit crop options. [23]

6.4.2 Improving crop competition

The impact of weeds on crop yield can be reduced and the effectiveness of weed-control tactics increased by crop competition. The rate and extent of crop canopy development are key factors influencing a crop's competitive ability with weeds. A crop that rapidly establishes a vigorous canopy, intercepting maximum sunlight and shading the ground and inter-row area, will provide optimum levels of competition.

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

Canopy development is influenced by:

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

Each factor will in turn affect plant density, radiation adsorption, dry matter production and yield. Early canopy closure can be encouraged through good management addressing the above factors.

Key issues:

- Good agronomy generally means a competitive crop.
- A competitive crop greatly improves weed control by reducing weed biomass and seedset (Figure 3).

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

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

- Different crops and varieties compete with and suppress weeds differently.
- High crop sowing rates reduce weed biomass and weed-seed production and may improve crop yield and grain quality. Optimising for yield and quality is advised.
- Take care to sow seed at optimum depth.
- Fertiliser placement can improve crop growth, yield and competitive ability.
- Many studies show a reduction in weeds with increased sowing rate and narrower rows.
- Furrow-sowing or moisture-seeking techniques at sowing can help establish the crop before the weeds.
- Sowing at the recommended time for the crop type and variety maximises crop competitive ability, which will reduce weed biomass and seedset.
- When delaying sowing to allow for control of the first germination of weeds, choose the crop type and variety most suited to later sowing to minimise yield loss.
- Sow problem weedy paddocks last to allow a good weed germination and subsequent kill prior to sowing.

A summary table of some of the key research in Australia to assess the effect of increasing crop sowing rate in the presence of weeds can be found in IWM Section 3: Agronomy.

Figure 5: Common sowthistle growing in-fallow (no competition) v. growing in-crop (wheat and barley), Condamine, Qld. There was no in-crop herbicide applied to control the weed. The lack of sowthistle in-crop is entirely due to crop competition. The season had a relatively dry start, so the crop established before the weeds. (Photo: M. Widderick)

6.4.3 Crop type

Crops with herbicide-tolerance traits bred using conventional methods have been used in Australia for many years. They include imidazolinone-tolerant (IT) wheat (Clearfield®), introduced in 2001.

Herbicide-tolerant crops are tolerant to a herbicide that would normally cause severe damage. Thus, they offer the option of weed-control tactics from different herbicide MOA groups that would not normally be able to be used in these crops.

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

Specific herbicide-tolerance crop-technology stewardship programs are a source of more detailed information. For example, the Clearfield® Stewardship Program.

Advantages of herbicide-tolerant crops:

- They provide additional crop choice, enabling use of alternative weed management tactics.
- They can sometimes enable a crop type to be grown where herbicide residues may be present in the soil from a previous crop.
- They can reduce the total amount of herbicide used and/or weed-control costs.
- They provide another option to use some herbicides. This should always be used in an IWM program and within the guidelines for the relevant stewardship program for that technology

Herbicide-resistance management guidelines for Australia for MOA groups can be downloaded from the CropLife Australia Limited website.

Some requirements of the stewardship packages include:

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

6.4.4 Improving pasture competition

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

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

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

6.4.5 Fallow phase

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

Benefits:

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

Key factors for success:

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

For Southern and Western Regions, further information can be found in the Summer Fallow Weed Management Manual. [24]

6.4.6 Controlled traffic for optimal herbicide application

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

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

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

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

In wide-row controlled-traffic systems, inter-row-shielded and band spraying as well as inter-row tillage may be options. Precision-guidance technology potentially makes such options more practical, but there are very few registrations allowing use of herbicides in this manner. [25]

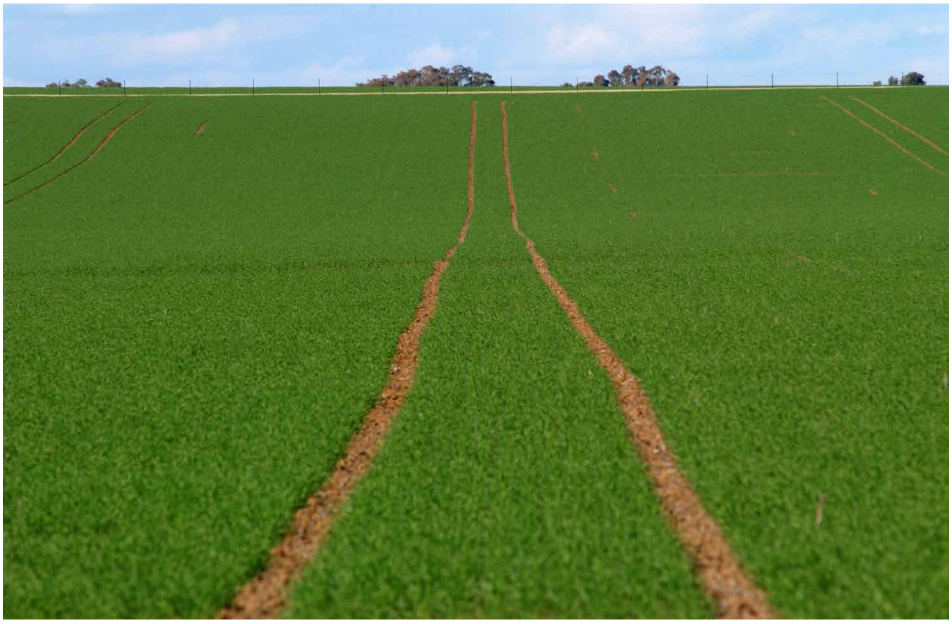

Figure 6: Controlled traffic cropping allows more options for weed control and management. (Photo: A. Mostead)

6.5 Key weeds in Australia's cropping systems

Annual ryegrass (*Lolium rigidum*)

Barley grass (*Hordeum* spp.)

Barnyard grasses (*Echinochloa* spp.)

Black bindweed (*Fallopia convolvulus*)

Click on each weed for more information

More information

GRDC: Summer fallow weed management manual

Integrated Weed Management Section 3: Agronomy

GRDC Fact Sheets
Break crop benefits. Western Region

Group A herbicides in fallow

Choosing break crops. Southern Region

Crop placement and row spacing. Southern Region

Summer fallow spraying. Northern, Southern and Western Regions

Time of sowing. Northern, Southern and Western Regions

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

GRDC Update Papers

Biology and management of summer weeds

Compete with weeds—give your crop heaven and your weeds hell

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

Impact of crop residues on summer fallow weeds

Landscape and weed influence on pest and beneficial insect populations

Non-herbicide tactics to help suppress weed growth

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

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

GRDC Update Papers

[Progress in developing weed competitive wheat]

[Seeding systems and pre-emergence herbicides]

[Summer weeds reduce moisture and nitrogen]

[Using crop competition for weed control in barley and wheat]

More information

[AGT: Weed tolerance and suppression in wheat]

[AWC research paper: Canola competition for weed suppression]

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

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

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

[AWC research paper: Weed suppression by crop competition in three crop species in Western Australia]

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

[WeedSmart You Tube video: Diverting weed seed onto permanent tramlines]

Bladder ketmia (*Hibiscus trionum*)

Brome grass (*Bromus* spp.)

Capeweed (*Arctotheca calendula*)

Doublegee (*Emex australis*)

Feathertop Rhodes grass (*Chloris virgata*)

Fleabane (*Conyza* spp.)

Fumitory (*Fumaria* spp.)

Indian hedge mustard (*Sisymbrium orientale*)

Liverseed grass (*Urochloa panicoides*)

Muskweed (*Myagrum perfoliatum*)

Paradoxa grass (*Phalaris paradoxa*)

Silver grass (*Vulpia* spp.)

Sweet summer grass (*Brachiaria eruciformis*)

Turnip weed (*Rapistrum rugosum*)

Wild oats (*Avena fatua* and *A. ludoviciana*)

Wild radish (*Raphanus raphanistrum*)

Windmill grass (*Chloris truncata*)

Wireweed (*Polygonum aviculare* and *P. arenastrum*) [26]

6.6 Stopping weed seedset

6.6.1 Seedset control tactics

Seedset control tactics include spray-topping with selective and non-selective herbicides, wick wiping, windrowing and crop desiccation, and techniques such as hand-roguing, spot-spraying, green and brown manuring, hay or silage production and grazing. Harvest weed-seed control tactics include narrow windrow burning, chaff-lining and chaff carts.

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

In-crop management of weed seedset is used to minimise the replenishment of seedbanks and/or reduce grain contamination. This is achieved by intercepting the seed production of weeds that have escaped, survived or emerged after application of weed-management tactics earlier in the cropping season.

Controlling weed seedset contrasts with early in-crop weed management tactics, which aim to maintain or maximise crop yield by reducing weed competition. There is minimal grain yield benefit in the current crop from seedset control tactics, because most weed competition occurs earlier during the vegetative stages of the crop. For this reason, seedset control tactics should always be used with other types of tactic. [27]

6.6.2 Selective spray-topping

Selective spray-topping is the application of a post-emergent, selective herbicide to weeds at reproductive growth stages to prevent seedset of certain weeds. The technique is aimed at weed seedbank management (i.e. reducing additions to the weed seedbank) but with minimal impact on the crop.

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

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

Selective spray-topping largely targets broadleaf weeds (especially *Brassica* weeds). The tactic should not be confused with pasture spray-topping, which occurs in a pasture phase, involves heavy grazing, uses a non-selective herbicide and largely targets grass weeds (see spray-topping in IWM Section 4: Tactics).

The strategy can be used to control 'escapes', as a late post-emergent salvage treatment, or for managing herbicide resistance.

The rapid spread of Group B resistance in *Brassica* weeds and Group A and Z resistance in wild oat (Avena spp.), along with the uncertain supply of the herbicide Mataven® (flamprop-M-methyl; for wild oats), has significantly reduced the potential application of this tactic (see below: *6.6 Herbicide resistance*).

Wild radish seeds can be viable once an embryo is visibly formed in the pod. This can occur within 21 days of flowering. [28]

6.6.3 Weed wiping

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

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

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

Weed wipers have developed significantly and include models with multiple ropes, carpets, sponges, revolving cylinders and pressurised supply, which make them significantly more effective. [29]

More information

IWM Section 4. Tactics

INLAND: Eliminator weed wiper

C-Dax Eliminator weed wiper

Figure 7: Blanket wipers use a sheet (blanket) moistened with herbicide to wipe the weeds above the crop. (Photo: A. Storrie)

6.6.4 Crop desiccation and windrowing

Crop desiccation with a non-selective herbicide and windrowing (also called 'swathing') are harvest aids; the growth stage of any weeds present is not a consideration. However, if conducted when weeds are green and growing, windrowing and crop desiccation can significantly reduce weed seedset.

These tactics are conducted at or just after crop physiological maturity. The greatest levels of weed control will occur if the crop matures before the weeds, so short-season cultivars are best suited.

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

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

Windrowing and desiccation can:

- encourage even ripening of crops
- increase harvest speed and efficiency
- minimise yield loss from shattering or lodging
- enhance seed quality
- overcome harvest problems caused by late winter or early summer weed growth
- minimise weather damage during harvest by increasing the speed of drying, while protecting the crop in the windrow
- improve the yield of following crops by halting water use by the current crop. Crops can continue to use soil water when past physiological maturity.

Any weed regrowth must be controlled to minimise seed production.

Harvest withholding periods must be known before using herbicides for crop desiccation. [30]

See IWM Section 4: Tactics.

6.6.5 Manuring, mulching and hay freezing

Sacrificing of a portion of the crop as a way to manage weed patches that have escaped control can be an effective management tool.

Crops and pastures can be returned to the soil by burial, mulching or chemical desiccation with the key aims of reducing weed seedbanks, improving soil fertility and maintaining soil organic matter.

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

Mulching is similar to brown manuring but involves mowing or slashing the crop or pasture and leaving the residue laying on the soil surface.

Hay freezing is similar to brown manuring with the additional aim of creating standing hay. In this case, herbicide is applied earlier than if the crop were to be mown for conventional haymaking.

If performed before weed seedset and all weed regrowth is controlled, reductions in weed seedset of >95% are possible. [31]

Figure 8: Hay cutting (left) and brown manuring (right)—two options to stop weed seedset. (Photo: A. Douglas)

More information

IWM Section 4: Tactics

GRDC Fact Sheets: Manuring of pulse crops

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

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

6.7 Pasture seedset control

6.7.1 Pasture spray-topping

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

Pasture spray-topping is possible because annual grasses become more sensitive to non-selective knockdown herbicides during flowering. This increased sensitivity allows lower rates of herbicide to be used to prevent the formation of viable grass seeds, with limited effect on desirable pasture species.

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

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

Although pasture spray-topping is targeting a different plant growth stage, i.e. flowering and seedset, a plant already resistant to that herbicide MOA will exhibit little or no effect. [32]

See IWM Section 4: Tactics.

6.7.2 Silage and hay

Silage and haymaking can be used to manage weeds by:

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

Silage and haymaking can reduce weed seed numbers by >95% if conducted before weed seedset, and any regrowth is controlled by herbicide or heavy grazing. [33]

See IWM Section 4: Tactics.

Figure 9: Silage in field peas to control resistant ryegrass and radish at Collie NSW (Photo: Penny Heuston)

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

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

6.7.3 Grazing to manage weeds actively

Grazing management can aid weed management, especially in a crop so suited to grazing as oats, by:

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

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

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

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

- grazing pressure often not high enough to prevent selective grazing (Figure 7)
- incorrect timing of practices to obtain the desired level of weed control
- risk of livestock importing weeds or transporting them to other paddocks [34]

Figure 10: Sheep are effective weed managers if stocking rates can be kept high enough. (Photo: A. Storrie)

More information

IWM Section 4: Tactics

GRDC Fact Sheets: Manuring of pulse crops

GRDC Update Papers: Fodder rotations with cropping to manage weeds

6.8 Herbicide resistance

Herbicide resistance is a major threat across Australia's grain regions for both growers and agronomists. For most herbicide MOAs, more than one resistance mechanism can provide resistance, and within each target site, a number of amino acid modifications provide resistance. This means that resistance mechanisms can vary widely between

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

populations; however, some patterns are common. Although some broad predictions can be made, a herbicide test is the only sure way of knowing which alternative herbicide will be effective on a resistant population. [35]

Recent resistance screening by the GRDC funded Grain Orana Alliance or GOA in 2014 of 51 samples resulted in the disturbing picture painted in the below table. Samples were taken from across the Central west of NSW.

Table 4: The number of annual ryegrass samples demonstrating resistance to the various herbicides and rates tested [36]

	10% Survival	survival
Trifluralin @ 2000ml/ha	1	2
Verdict 100ml/ha	44	86
Select® 350ml/ha	31	61
Select® 500ml/ha	13	26
Factor® 180g/ha	7	14
Axial® 300ml/ha	39	77
Logran 750® 35g/ha	46	90
Hussar OD® 100ml/ha	44	86
Intervix® 750ml/ha	30	59
Atrazine 900 WG 2000g/ha	19	37
Glyphosate 540 1000ml/ha	29	57
Glyphosate 540 1500ml/ha	9	18
Glyphosate 540 2000ml/ha	4	8

6.8.1 Testing services

For testing of suspected resistant samples, contact:

Charles Sturt University Herbicide Resistance Testing
School of Agricultural and Wine Sciences
Charles Sturt University
Locked Bag 588
Wagga Wagga, NSW 2678
02 6933 4001
http://www.csu.edu.au/weedresearchgroup/herbicide-resistance

Plant Science Consulting
22 Linley Ave
Prospect, SA 5082
0400 664 460
info@plantscienceconsulting.com.au, www.plantscienceconsulting.com

6.8.2 Ten ways to weed out herbicide resistance

1. Act now to stop weeds from setting seed:
   - Destroy or capture weed seeds.
   - Understand the biology of the weeds present.
   - Remember that every successful WeedSmart practice can reduce the weed seedbank over time.
   - Be strategic and committed—herbicide-resistance management is not a 1-year decision.
   - Research and plan your WeedSmart strategy.

35 C Preston (2014) The mechanisms of herbicide resistance. GRDC Update Papers, 5 March 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/The-mechanisms-of-herbicide-resistance

36 M Street, B Obrien (2014) Report on the 2014 GOA herbicide resistance survey. Grain Orana Alliance/GRDC, http://www.grainorana.com.au/documents?download=35

- You may have to sacrifice yield in the short term to manage resistance—be proactive.
- Find out what other growers are doing, and visit www.weedsmart.org.au.

2. Capture weed seeds at harvest. Options to consider are:
   - Tow a chaff cart behind the header.
   - Check out the new Harrington Seed Destructor.
   - Create and burn narrow windrows.
   - Produce hay where suitable.
   - Funnel seed onto tramlines in controlled traffic farming systems.
   - Use a green or brown manure crop to achieve 100% weed control and build soil N levels.
3. Rotate crops and herbicide MOAs:
   - Look for opportunities within crop rotations for weed control.
   - Understand that repeated application of effective herbicides with the same MOA is the single greatest risk factor for evolution of herbicide resistance.
   - Protect the existing herbicide resource.
   - Remember that the discovery of new, effective herbicides is rare.
   - Acknowledge that there is no quick chemical fix on the horizon.
   - Use break crops where suitable.
   - Growers in high-rainfall zones should plan carefully to reduce weed populations in the pasture phase prior to returning to cropping.
4. Test for resistance to establish a clear picture of paddock-by-paddock weed status:
   - Sample weed seeds prior to harvest for resistance testing to determine effective herbicide options.
   - Use the 'Quick Test' option to test emerged ryegrass plants after sowing to determine effective herbicide options before applying in-crop selective herbicides.
   - Visit the WeedSmart website, http://www.weedsmart.org.au/ or www.ahri.uwa.edu.au for more information on herbicide-resistance survey results.
5. Aim for 100% weed control and monitor every spray event:
   - Stop resistant weeds from returning into the farming system.
   - Focus on management of survivors in fallows.
   - Where herbicide failures occur, do not let the weeds seed. Consider cutting for hay or silage, fallowing or brown manuring the paddock.
   - Patch-spray areas of resistant weeds only if appropriate.
6. Do not automatically reach for glyphosate:
   - Use a diversified approach to weed management.
   - Consider post-emergent herbicides where suitable.
   - Consider strategic tillage.
7. Never cut the on-label herbicide rate and carefully manage spray drift and residues:
   - Use best management practice in spray application. Consult GRDC Fact Sheets, available at www.grdc.com.au.
   - Consider selective weed sprayers such as WeedSeeker® or WEEDit®.
8. Plant clean seed into clean paddocks with clean borders:
   - It is easier to control weeds before the crop is planted.
   - Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
   - A recent Australian Herbicide Resistance Initiative (AHRI) survey showed that 73% of grower-saved crop seed was contaminated with weed seed.
   - The density, diversity and fecundity of weeds are generally greatest along paddock borders and areas such as roadsides, channel banks and fence lines.

9. Use the double-knock technique:
   » Double-knock is the use of any combination of weed control that involves two sequential strategies; the second application is designed to control survivors of the first method of control used.
   » Access GRDC research results at www.grdc.com.au or www.nga.org.au.
10. Employ crop competitiveness to combat weeds:
   » Consider narrow row spacing and seeding rates.
   » Consider twin-row seeding points.
   » Use high-density pastures as a rotation option.
   » Consider brown manure crops.
   » Rethink bare fallows. [37]

6.9 Managing the weed seedbank

The weed seedbank is defined as the mature seeds that exist in the soil. At any given time, the soil seedbank contains viable weed seeds produced in several previous years (the seedbank). These seeds (of different ages) will either be able to germinate when the conditions are favourable (suitable temperature, adequate water and enough oxygen) or be dormant.

When new seed is prevented from entering the seedbank, persistence can be determined by measuring the time taken for the number of weed seeds in the soil to diminish to negligible levels. This will vary with weed species due to the differing levels and types of dormancy.

There are two ways to diminish the seedbank:

- Weed seed germination and subsequent seedling emergence. Factors including light, soil conditions such as temperature and moisture, the soil's gaseous environment and nutrient status all affect the seed's dormancy and ability to germinate. Tillage can affect seed germination by redistributing the seed to a different profile in terms of moisture, temperature, etc. or changing the amount of available light. Autumn tickle stimulates germination of some weed species by placing seed in a better physical position in the soil. (Note: this is not applicable to surface-germinating weeds.) A well-timed autumn tickle will promote earlier and more uniform germination of some weed species for subsequent control. Tickling often needs to be used in conjunction with delayed sowing.
- Seed loss other than germination. Most seeds fail to emerge as seedlings. Some are buried at depths too great to permit emergence, and a large fraction simply lose viability over time and die of old age. After long-term reduced tillage or no-tillage, most weed seed is at or close to the soil surface.

Some weed seeds may also be eaten or attacked by pathogens. A study in the Western Australian wheatbelt found that 81% of the original annual ryegrass seed and 46% of wild radish seed had been removed by ants (seed predation).

Natural mortality rates of weed seed are far higher in no-till systems where weed seed is left on the soil surface than in systems where weed seed is mixed in the top few centimetres of soil. Burying some types of weed seeds can increase seedbank dormancy and slow the rate at which the seedbank is depleted. [38]

6.9.1 Burning residues

Fire can be used to kill weed seeds on the soil surface if there is sufficient fuel load and the fire is hot enough (Figure 8). Burning over summer poses an unduly high fire hazard and is illegal in most regions. An autumn burn often poses a lower fire hazard

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

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

and leaves crop residue in place to protect soil from wind and water erosion for a longer period. Maintaining stubble for longer also benefits soil water capture and retention, provided summer weed growth is controlled.

To obtain high levels of control of weeds such as annual ryegrass and wild radish, a hot fire is needed. This is obtained by windrow burning, where crop residues from cereal, canola or pulse crops is concentrated with weed seed in a narrow windrow and then burnt. [39]

Figure 11: Chaff dumps can be burnt in autumn killing a high proportion of seeds present. (Photo: A. Storrie)

6.9.2 Encouraging insect predation of seed

The contribution that insects make to seedbank reduction is often overlooked, despite weed seeds comprising a major component of many insect diets (Figure 9). This predation of seed contributes to 'natural mortality' and partly explains why less seed germinates than is produced.

Understanding the role that insects play in removing weed seeds could help the development of farming systems that encourage greater removal of seeds from the seedbank. In New South Wales, seed theft by ants has commonly caused failure of pastures, and data from Western Australia show that ants can remove 60% or more of annual ryegrass in no-till systems, where weed seed is on the soil surface and accessible. Therefore, weed seedbanks could be also decreased by encouraging ant predation. [40]

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

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

Figure 12: Grass seeds collected by ants. (Photo: A. Storrie)

6.9.3 Delayed sowing

Delayed sowing (seeding) is the technique of planting the crop beyond the optimum time for yield in order to maximise weed emergence and control prior to sowing. Weeds that emerge in response to the break in season can then be killed by using a knockdown herbicide, where resistance is not an issue, or cultivation prior to crop sowing (Figure 10).

This tactic is most commonly employed for paddocks that are known to have high weed burdens. Paddocks with low weed burdens are given priority in the sowing schedule, leaving weedy paddocks until later. This allows sufficient delay for the tactic to be beneficial on the problem paddock without interrupting the whole-farm sowing operation.

Choosing a crop or cultivar with a later optimum sowing time can reduce yield impact of a later sowing date. [41]

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

Figure 13: Delayed sowing allows use of knockdown herbicides or cultivation to control small weeds prior to sowing, reducing the pressure on selective in-crop herbicides. (Photo: D. Holding)

6.10 Managing weed seedlings

Killing weeds with cultivation has been the focus of weed management since agriculture was first developed. Since the release of glyphosate and Group A and B herbicides in the early 1980s, herbicides have been the primary tool for controlling weeds because they are cost effective, do not disturb soil and crop residue, have high levels of control and are easy to use. However, this approach to controlling weeds has led to the development of herbicide resistance. Despite herbicide resistance, herbicides remain an important tool, but require support from a range of non-herbicide tactics to remain effective.

Tactics that assist include fallow, pre-sowing and interrow cultivation, double-knock, alternate pre- and post-emergent herbicides, roguing individual plants, weed-detector spraying, and harvest weed-seed control

'Used alone, none of the currently available cultural techniques provide an adequate level of weed control. However when used in carefully planned combinations extremely effective control can be achieved.' (Gill and Holmes 1997) [42]

6.10.1 Killing weeds with tillage

Cultivation can kill many weeds, including herbicide-resistant and hard-to-kill populations. Cultivation is useful as a 'one-off' tactic in reduced-tillage or no-till operations. Well-timed cultivation in a no-till system can give a range of benefits with manageable reduction on conservation farming goals. [43] Planned cultivation can also be used as a non-herbicide component of a double-knock system (see IWM Section 4: Tactics).

Benefits

1. Well-timed cultivation in a drying soil effectively kills weeds. Cultivation destroys weeds in a number of ways, including:
   - plant burial
   - seed burial, thus reducing the ability to germinate if sufficiently deep

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

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

» severing roots
» plant desiccation, where plants are left on the soil surface to die
» breaking seed dormancy or seed being placed in a more favourable environment to encourage germination for subsequent control

2. In preparing a seedbed, cultivation provides a weed-free environment for the emerging crop and can improve soil surface conditions for even application of pre-emergent herbicides.
3. Cultivation can control weeds in situations where herbicides are ineffective or not an option.
4. Pre-sowing cultivation or full disturbance cultivation at sowing reduces reliance on knockdown herbicides and therefore the likelihood of weed populations developing herbicide resistance.
5. Shallow cultivation to incorporate pre-emergent herbicides reduces loss due to volatilisation and photodegradation.

Whole-farm benefits

Weed management can have an additional benefit where cultivation is used for:

- incorporating soil ameliorants (e.g. lime or gypsum)
- overcoming stratification of non-mobile nutrients such as phosphorus or redistribution of potassium that has been concentrated in surface zones after years of no-till if the cultivation is to a sufficient depth
- breaking up a hard pan or subsoil restriction

Issues with tillage

The term ‘strategic tillage’ has been widely quoted. In many instances when tillage is used to combat herbicide-resistant weeds, the timing of tillage is driven more by weed escapes than by good planning:

- Using tillage at the start of a summer fallow will degrade soil cover, leaving the soil more exposed to wind and water erosion and evaporation over the summer period.
- In wet soil conditions, the percentage weed kill delivered by tillage is often poor due to replanting of weeds back into moist soil.
- Compaction can occur, particularly in wet soils.
- Soil structure can be compromised, in particular infiltration resulting in less stored fallow moisture
- It speeds breakdown of stubble and reduces protection from water and wind erosion.
- In the weeks prior to sowing, it can lead to a loss of soil water needed for crop establishment.
- In cracking clay soils, tillage can close surface cracks and reduce the soil’s ability to accept high-intensity, summer storm rainfall, with ensuing runoff and soil loss.
- Tillage will bury weed seeds, which may prolong seedbank dormancy in many weed species and can reduce efficacy of some pre-emergent herbicides used at sowing.
- Tillage often costs more, requires greater capital investment and more labour, and is slower than spraying.

Tillage works best in dry or drying soil environments. Weeds are easier to kill when small with smaller root systems. Larger plants may need a more aggressive implement and/or multiple passes. [44]

More information

GRDC Fact Sheets: Strategic tillage

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

6.10.2 Killing weeds with herbicides

The rapid development of resistance to glyphosate in several weeds has placed increased reliance on in-crop weed management. Many selective herbicides already have resistance issues; therefore, an increase in reliance on pre-emergent herbicides is forecast while these remain effective.

The last significant new MOA groups released into the Australian herbicide market were Group B, when chlorsulfuron was launched in 1982, and Group H in 2001. No new post-emergent herbicides appear anywhere near commercialisation, so it is clear that the supply of new chemistries is limited.

The only new MOAs on the horizon (and they are not great in number) are all pre-emergent chemistries.

Hence, we need to look after what is available for as long as possible. [45]

Further information on registered chemicals can be obtained from APVMA and CropLife Australia, and Regional weed control references.

Knockdown (non-selective) herbicides for fallow and pre-sowing control

Knockdown herbicides are key tools to enable no-till fallows to be managed economically and efficiently. They are also used in the crop, especially glyphosate in RR crops or as a late, in-crop salvage spray.

Knockdown herbicides also represent a key component of other weed management tactics, including:

- controlling weeds before sowing (see delayed sowing and agronomy in IWM Section 3)
- herbicide-tolerant crops (agronomy)
- controlling weeds in fallow (agronomy)
- use of wiper methods (see tactic 3.1 in IWM Section 4)
- crop desiccation (see tactic 3.1)
- pasture spray-topping (see tactic 3.2)
- brown manuring and hay freezing (see tactic 3.4)

Since its release in the late 1970s, glyphosate has become the most widely used herbicide in the world. Prior to this, paraquat was more commonly used. Developed to deal with capeweed in southern Australian farming systems, SPRAY.SEED® (paraquat + diquat) also improved the control of *Erodium* spp., capeweed (*Arctotheca calendula*) and black bindweed (Fallopia convolvulus) over paraquat used alone.

In unselected weed populations, genes carrying resistance to glyphosate are rare, and selection for 15+ years is required before the frequency of resistant individuals is likely to lead to a spray failure.

The Australian Glyphosate Sustainability Working Group provides up-to-date information on glyphosate and paraquat resistance.

With widespread use over a prolonged period and often few if any other measures taken to control weed escapes, populations of weeds resistant to glyphosate have increased exponentially. This increase is forecast to continue.

In winter crop, no-till rotations, the selection pressure for resistance to glyphosate is placed more on summer weeds. Glyphosate resistance has developed in multiple grass weeds as well as fleabane. No-tillage has enabled the wheat belt to expand into lower rainfall rangeland country because it has enabled far better management and storage of limited rainfall. Increasingly, however, widespread resistance to glyphosate threatens the base technology of many current cropping systems.

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

More information

GRDC: Summer fallow weed management

With widespread use of herbicides comes increased potential for spray drift. Weather conditions, droplet size, proximity to adjoining crops are critical issues. [46]

Double-knockdown or double-knock

Double-knock is the sequential application of two different weed-control tactics where the second tactic controls any survivors from the first tactic.

An example in common use is the sequential application of glyphosate (Group M) followed by paraquat or a paraquat/diquat mix such as Sprayseed ® (Group L), at an interval of 1–14 days. Each herbicide must be applied at a rate sufficient to control weeds if it were used alone. The second herbicide is applied to control any survivors from the first herbicide application. Control of weeds that germinate during the interval between the two applications of herbicide is an incidental benefit.

Other double-knock strategies include following a herbicide with burning or grazing, or seed capture and removal or burning.

Double-knock strategies delay the onset of herbicide resistance; however, modelling shows that if many years of selection take place in which survivors of glyphosate applications are allowed to set seed before double-knock strategies are used, the benefit of double-knock as a delaying strategy for the onset of resistance to glyphosate is greatly diminished. [47]

Using a double-knock strategy reduces the number of glyphosate-resistant weeds to be controlled in-crop and improves the general level of weed control obtained.

Some key grass and broadleaved weeds can only be reliably controlled using double-knockdown sprays.

Populations of grass weeds that have developed resistance to glyphosate:

- annual ryegrass (*Lolium rigidum*)
- awnless barnyard grass (*Echinochloa cruss-galli*)
- great brome grass (*Bromus* spp.)
- red brome (*Bromus rubens*)
- liverseed grass (*Urochloa panicoides*)
- windmill grass (*Chloris truncata*)
- flaxleaf fleabane (*Conyza bonariensis*)
- wild radish (*Raphanus raphanistrum*)
- sowthistle (*Sonchus* spp.)

Weeds that are naturally tolerant of glyphosate:

- feathertop Rhodes grass (*Chloris virgata*)

Fleabane can be effectively controlled in the early rosette stage by double knockdown where paraquat alone or in-mix with diquat is applied 5–7 days after glyphosate that has been mixed with a suitably efficacious Group I herbicide.

Key issues for double-knock

Where glyphosate and paraquat are appropriate products to use, glyphosate should be applied first and followed by paraquat or paraquat–diquat.

The ideal time between applications will vary with the main target weed species.

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

[47] DT Thornby, SR Walker, JPM Whish (2008) Modeling to estimate glyphosate resistance risk in barnyard grass in the northern Australian grain region. *Proceedings of the 16th Australian Weeds Conference*, http://www.caws.org.au/awc/2008/awc200815131.pdf

Almost all annual species benefit from 1 day or more between applications. In some species, longer delays of 1–2 weeks are beneficial, but delaying too long can lead to regrowth of weeds and poorer results.

Apply the first herbicide when the weeds are most likely to be killed, i.e. when small and actively growing.

Maximum control of annual ryegrass results from an application of herbicide at the 3–4-leaf stage. Annual ryegrass sprayed at the 0–1-leaf stage can regrow from seed reserves. Later application, when the annual ryegrass is tillering, risks incomplete control because little translocation takes place within the plant.

When applying contact herbicides or Group A herbicides, increase spray carrier volume and avoid very coarse droplet sizes, because excellent spray coverage is needed for success. Seasonal conditions and spraying capacity will influence the scale of on-farm implementation.

More information

GRDC: Summer fallow weed management

Target this tactic to paddocks with the highest weed populations because these are at higher risk of selection for resistance.

Be aware that use of double-knock strategy on a percentage of land each year will add logistical stress to spray operations. This needs to be planned for. [48]

Pre-emergent herbicides

Pre-emergent herbicides control weeds at the early stages of the life cycle, between radical (root and shoot) emergence from the seed and seedling leaf emergence through the soil.

Some pre-emergent herbicides also have post-emergent activity through leaf absorption and they can be applied to newly emerging weeds.

The residual activity of a pre-emergent herbicide controls the first few flushes of germinating weeds (cohorts) while the crop is too small to compete. As a result, pre-emergent herbicides are often excellent at protecting the crop from early weed competition.

Factors to consider when using pre-emergent herbicides:

- Weed species and density. Knowing which weeds to expect is critical. Pre-emergent herbicides are particularly useful at stopping early weed competition, especially if high weed densities are expected.
- Crop or pasture type. What is registered, how competitive is the crop, and which post-emergent options exist?
- Soil condition. Cloddy soil surfaces, large amounts of stubble or an excess of ash from stubble burning can affect the performance of some pre-emergent herbicides. Less soluble herbicides such as simazine need to be mixed with the topsoil, generally via sowing, for best results. The more mobile herbicides such as sulfonylureas and imidazolinones may not need mechanical incorporation, because they move into the topsoil with water (rain or irrigation). Some herbicides need incorporation or coverage to prevent UV losses (e.g. atrazine) or volatilisation (e.g. trifluralin).
- Rotation of crop or pasture species. All pre-emergent herbicides persist in the soil to some degree. Some post-emergent herbicides may also persist in the soil. Consequently, herbicides may carry over into the next cropping period. The time between spraying and safely sowing a specific crop or pasture without residual herbicide effects (the plant-back period) varies, depending on herbicide, environmental conditions and soil type.

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

More information

IWM Section 4: Tactics

The following influence the fate of herbicides in the soil (Table 5):

- herbicide adsorption and solubility
- herbicide mechanism of breakdown (i.e. chemical or microbial)
- soil texture
- soil pH (for some herbicides)
- organic matter
- previous herbicide use
- soil moisture
- initial application rate
- soil temperature
- volatilisation
- photodegradation

Table 5: Soil attributes that contribute to herbicide availability

Higher herbicide availability	Lower herbicide availability
Sandy soils	Clay soils
Low organic matter	High organic matter
High pH (triazines and sulfonyl ureas)	Low pH
Low pH (imidazolinones)	High pH
Wet conditions	Dry conditions

When using pre-emergent herbicides, consider how the herbicide kills weeds, how it gets into the weed zone and where it will be when weeds are germinating (Table 6). Typically, situations that reduce availability will require higher application rates to achieve equivalent control. Properties that reduce availability also tend to increase the length of herbicide persistence in the soil, thus increasing rotational crop constraints.

A pre-emergent herbicide that is sitting on a dry soil surface at the time of weed emergence is unlikely to have sufficient soil moisture for uptake by the weed or sufficient contact with the emerging weeds to kill them. This might occur if the herbicide was applied immediately post-sowing while weeds were already germinating and if there was no rain or mechanical incorporation to take the herbicide into the germination zone where it can be taken up by the young weeds. Weed escapes in such situations are likely.

Crop safety is also an important issue when using pre-emergent herbicides. Crop tolerance of several pre-emergent herbicides (i.e. trifluralin, pyroxasulfone, prosulfocarb) is often related to spatial separation of the young crop from the herbicide. This, in turn, is related to the solubility and potential movement in the soil of the herbicide, the crop establishment process, the level of soil displacement over the crop row, follow-up rainfall and the physical nature of the seed furrow. [49]

[49] Section 4. Managing weed seedlings. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-4-Managing-weed-seedlings

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Table 6: Positive and negative aspects of using pre-emergent herbicides

Positive	Negative
Relatively inexpensive	Strongly dependent on soil moisture
Optimises crop yield through control of early weed germinations	Because weeds are not yet visible, must have paddock history/knowledge of previous weeds/ weed seedbank
Different modes of action to most post-emergent herbicides	Plant-back periods limit crop rotation
Timing of operation: generally have a wide window of opportunity for application options	Crop damage if sown too shallow or excessive quantities of herbicide move into root-zone
Best option for some crops where limited post-emergent options exist	Seedbed preparation: soil may need cultivation and herbicide may need incorporation, which can lead to erosion, soil structural decline and loss of sowing moisture
Effective on some weeds that are hard to control with post-emergent herbicides (e.g. wireweed and black bindweed)	Not suitable when dense plant residues or cloddy soils are present
Extended period of control of multiple cohorts; good for weeds with multiple germination times	Varying soil types and soil moisture across paddock can be reflected in variable results

Selective post-emergent herbicides

Selective post-emergent herbicides control emerged weeds in the crop or pasture.

The first selective post-emergent developed was a Group I herbicide, 2,4-D (released ~1945). Group A and B herbicides were released in the 1980s.

Selective post-emergent herbicides belong to MOA Groups A (e.g. diclofop), B (e.g. metsulfuron), C (e.g. diuron), F (e.g. diflufenican), G (e.g. carfentrazone), I (e.g. 2,4-D, dicamba, picloram), J (e.g. flupropanate) and R (e.g. asulam).

Many new selective post-emergent herbicides have been released in recent years; however, all of them have been from known MOA groups. No new post-emergent herbicides from new MOA groups are likely to be released in the near future.

Selective post-emergent herbicides give high levels of control (often >98%) when applied under recommended conditions on susceptible populations. When used early in crop development, at recommended rates and timings, selective post-emergent herbicides also result in optimum yield with potential for significant economic returns.

Early use on small susceptible weeds improves control levels achieved and removes weeds before significant crop yield loss occurs.

In addition to post-emergent activity, some post-emergent herbicides have pre-emergent activity on subsequent weed germinations. This is particularly the case with some Group B, C, F and I herbicides. Group A products have sufficient residual activity that they may affect cereal crops if sown too soon after use.

When choosing a selective post-emergent herbicide for a particular situation, consider the following factors:

- target weed species and growth stage
- herbicide resistance status of target weeds
- crop safety (variety, environmental conditions, effect of previously applied herbicide on crop)
- grazing and harvest withholding periods and plant-back periods
- cost
- spray drift risk
- mix partners

Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.

Crops that are usually tolerant can be damaged when stressed by waterlogging, frost or dry conditions because they cannot produce sufficient levels of the enzymes that normally break the herbicide down; for example, when sulfonylureas are applied to cold and waterlogged crops and high levels of crop impact are seen. Group A herbicides often fail to kill weeds if applied too soon after a severe cold stress (frost).

Good crop competition improves the efficacy of post-emergent herbicides.

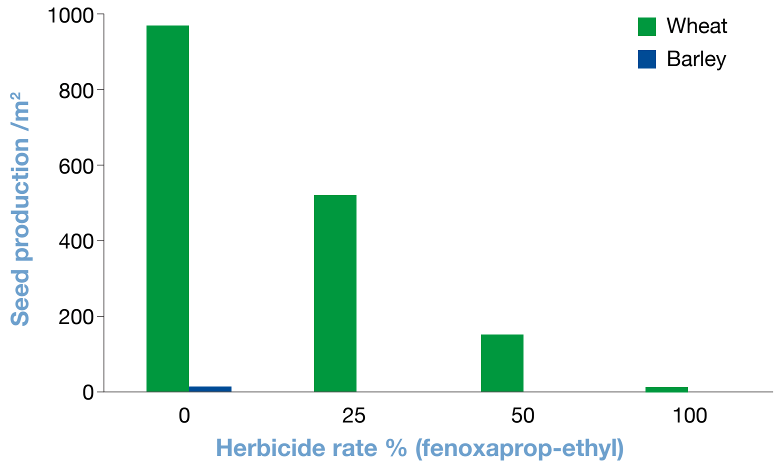

Figure 14: Effect of crop type and herbicide rate on paradoxa grass seed production. (Source: Walker et al. 1998)

When using selective post-emergent herbicides, it is important to use the correct application technique. Particular attention should be paid to:

- Equipment. Nozzles, pressure, droplet size, mixing in the tank, boom height and groundspeed should be set to maximise the efficiency of herbicide application to the target.
- Meteorological conditions. Suitable conditions are indicated by Delta T (ideally <8°C) when air movement is neither excessively windy nor still. (Delta T is an indication of evaporation rate and droplet lifetime and is calculated by subtracting the wet bulb temperature from the dry bulb temperature).

Spraying should not be conducted in inversion conditions and ideally should be done when temperatures are <28°C.

To get the best performance from the herbicide being applied, use the adjuvant recommended on the herbicide label. Because plants have different leaf surfaces, an adjuvant may be needed to assist with herbicide uptake and leaf coverage. Some adjuvants can also increase performance by lowering the pH, water hardness, compatibility, rain-fastness or drift. For more detailed information on adjuvants, see the GRDC publication Adjuvants—oils, surfactants and other additives for farm chemicals.

Selective post-emergent herbicides applied early and used as a stand-alone tactic often have little impact on weed seedbanks.

Early post-emergent herbicide use is aimed at maximising yield by removing weed competition at crop establishment stages. Any weed that germinates after or survives this application will set seed that will return to the seedbank, thus maintaining weed seedbank numbers and ensuring continuation of the weed problem.

6.10.3 Spot spraying, chipping, hand roguing and wiper technologies

When weed numbers are low or when still contained in patches, hand weeding, spot spraying and other methods, including selective crop destruction, can be used to stop weed seedset and seedbank replenishment.

Wiper technologies are useful when there is a height differential between the crop and weeds to allow a weed wiper to apply concentrated herbicide to the weed while avoiding contact with the crops plants.

Where new weed infestations occur in low numbers, eradication may be possible. In such situations, more intensive tactics to remove weeds can be used in addition to ongoing management tactics that aim to minimise weed impact.

Some key points:

- Stay vigilant for new or isolated weeds.
- Be prepared to hand-pull weeds, a not uncommon practice in WA for wild radish
- Keep a rubbish bag handy for weeds that already have seeds developed.
- Correctly identify new weeds and appropriate control measures.
- Manage and isolate outbreaks and hot spots.
- Stop weed seedset.
- Plan follow-up observation and management.
- Mark isolated weed patches by GPS and diary to check for later germinations. [50]

More information

Tactic 2.4 of IWM Section 4: Tactics

6.10.4 Weed-detector sprays

Weed detector sprayers are used for the control of scattered weeds in crop fallows. Weed-detector-activated sprayers detect the presence of weeds using infrared reflectance units linked to a single nozzle. When a weed is detected, a solenoid turns on an individual nozzle and the weed is sprayed.

This technology has been in use in the Northern Grains Region for a number of years, where it is reducing the volume of herbicide used in fallow per hectare by 80–95% depending on the density of the fallow weeds and the sensitivity settings of the sprayer.

This technology allows the use a range of herbicide MOAs and/or higher than usual rates while remaining economical.

Weed-detecting technology (via WeedSeeker®) is being used to manage glyphosate-resistant grasses in northern New South Wales fallows with the aid of a minor use permit. This allows growers in the region to use selective grass herbicides and higher rates of paraquat and diquat (bipyridyl herbicides, Group L).

A national APVMA minor use for the WeedSeeker® Permit (PER11163) has been obtained and is valid until February 2019 to cover all Australian states.. Go to the APVMA site and enter the permit number.

The permit allows the use of about 30 different herbicides from groups with seven MOA. Additional MOAs are likely to be added to the permit over time.

Some herbicide rates have been increased to enable control of larger or stressed weeds. For example, the glyphosate 450 (450 g glyphosate/L) rates are 3–4 L/ha (using a set water rate of 100 L/ha), which exceeds the label blanket rates of 0.4–2.4 L/ha. Similar increases in rate have also been permitted for paraquat (Gramaxone®).

The WeedSeeker® permit system is a lifesaver for no-till and minimum-tillage systems battling glyphosate-resistant weeds. It represents a more economical way to carry out a double-knock and avoids the need to cultivate for weed-seed burial.

The new technology also has the potential to map t roublesome weed patches so that these areas can be targeted with a pre-emergent herbicide before sowing.[51]

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

51 T Cook (2013) Selective spraying to cut costs. GRDC Ground Cover Supplements, 6 May 2013, http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS104/Selective-spraying-to-cut-costs

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

More information

[AWC: Inter- and intra-row herbicide application strategies for the control of annual ryegrass in wide-row faba beans]

[AWC: Pyroxsulam for broad-spectrum weed control in wheat]

[CSIRO: Overview—Biological control of weeds]

[GIWA: Natural and environmentally friendly way of managing weeds without herbicides]

[GRDC: Adjuvants—Oils, surfactants and other additives for farm chemicals]

[GRDC: Regional weed control references]

[GRDC: Summer fallow weed management]

[GRDC Ground Cover: Advice at hand for fallow grass-weed control]

[IWM Section 4: Tactics]

[QAAFI: Double knock for controlling flaxleaf fleabane]

[Syngenta: SPRAY.SEED®]

[Weeds Australia: Target species for biological control]

Some added benefits and issues of this technology include:

- Drift risk is lower because coarse droplets are used and only a low percentage of the paddock is sprayed.
- Infrared signal enables use at night. Group L herbicides are often used as the second spray in double-knock programs and they tend to be more effective when sprayed late afternoon, in the evening or under cloudy conditions. A disadvantage of night spraying is a greatly elevated risk of inversion drift conditions.
- Weeds in wheat stubble should be larger than ~ 5 cm for reliable detection.
- Maintaining correct boom height, staying within design travel speeds and avoiding spraying in strong winds are essential for reliable performance. [52]

6.10.5 Biological control

Biological control for the management of weeds uses the weed's natural enemies (biological control agents). These include herbivores, such as insects and sheep, where there is direct consumption of the weed. Natural enemies also include microorganisms such as bacteria, fungi and viruses, which can cause disease, reduce weed vigour and competitiveness relative to the crop, and decay the weed seed in the seedbank. Other plants can also be included here, where they release substances that suppress weed growth—this is known as allelopathy. [53]

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

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

GRDC Update Papers

Achieving good pre-emergent spray results

Getting the right mix

Hardseeded annual legumes

Herbicide efficacy in no-till farming systems in southern NSW

Herbicide management in the summer fallow

Herbicides for control of clethodim-resistant annual ryegrass

Hitting the right target—what are our most costly weeds?

New technology for improved herbicide use efficiency

NGA chickpea herbicide trials 2014

Pre-emergent herbicides and seeding system interactions

Protecting glyphosate in summer fallows—mixes with pre-emergent herbicides and double knocking trials

Seeding systems and pre-emergence herbicides

The strategic use of tillage in conservation farming

GRDC Fact Sheets

In-crop herbicide use (Northern, Southern and Western Regions)

Practical tips for spraying (Northern, Southern and Western Regions)

Pre-emergent herbicides (Northern, Southern and Western Regions)

Pre-harvest herbicide use (Northern, Southern and Western Regions)

Pre-season sprayer checks (Northern, Southern and Western Regions)

Spray equipment (Northern, Southern and Western Regions)

Spray height control (Northern, Southern and Western Regions)

Spray water quality (Northern, Southern and Western Regions)

Strategic tillage (Northern and Southern Regions)

Summer fallow spraying (Northern, Southern and Western Regions)

Weed control in wheel tracks (Northern, Southern and Western Regions)

GRDC Videos

Advances in weed management: Spray application in summer fallows

Advances in weed management: Stubble and soil binding of pre-emergent herbicides for annual ryegrass control in winter crops

Crop competition for weed management—narrow row spacings

Double knock applications—a grower's experience

Double knock applications—double knock strategies for resistant weed populations

Double knock applications—target weed species and application strategy

GCTV10: Double knock timing

GCTV11: Strategic tillage, does no-till mean never till?

Spray application of herbicides—application volume in stubble

Spray application of herbicides—applying Group A (ACCAse inhibitor) herbicides

Spray application of herbicides—nozzle selection

Spray application of herbicides—spray deposition

Spray application of herbicides—travel speed

Weed seed bank destruction—Weed Seeker

Videos

SANTFA: Summer weed control

WeedSmart: Understanding pre-emergent herbicides

WeedSmart: When is it worth rotating from Select to Factor?

6.11 Harvest weed-seed control

Controlling weed seeds at harvest is emerging as the key to managing the increasing levels of herbicide resistance, which are putting Australia's no-till farming system at risk.

For information on harvest weed-seed control and its application for the southern grains region, see *GrowNotes Wheat South Section 12. Harvest* .

6.12 Strategies to stop the spread of weeds

Risk-aware growers can implement strategies to reduce and avoid unnecessary introduction and spread of weeds.

Weed importation and spread can be impeded at several critical points, namely:

- sowing of the seed
- fencelines and non-cropped areas in cropping paddocks (e.g. water courses)
- machinery and vehicle usage
- stock feed and livestock movement
- in fields following floods and inundation

More information

IWM section 4: Tactics

A well-managed, on-farm hygiene strategy will address each of these elements.

6.12.1 Sow weed-free seed

Weed seed is regularly spread around and between farms as a contaminant of sowing seed. Seed for sowing is commonly grower-saved and usually contaminated with weed seeds, frequently at very high levels. Various 'seed-box' surveys have that less than a quarter of farmers surveyed sow weed-free seed. On average, ungraded seed had 25 times more foreign seeds than graded seed.

To avoid these problems follow the following guidelines:

- Know the weed status of any farm from which you buy seed.
- Plan seed purchases ahead of time and inspect the paddock where the seed is being grown.
- Obtain a sample of the seed and have it analysed for weed seed contamination and germination.
- Determine the herbicide-resistance status of weeds present on the source farm and paddock, and avoid purchasing seed from paddocks with known resistance.
- Grade seed to reduce weed numbers. [54]

More information

IWM section 4: Tactics

6.12.2 Manage weeds in non-crop areas

Weed infestations often commence in non-crop areas (e.g. around buildings, along roadsides, along fencelines, around trees) (Figure 16). Controlling these initial populations will prevent weeds from spreading to other parts of the property. These areas have become primary sources of glyphosate-resistant weeds, which then spread into paddocks. This is particularly important for weeds with wind-blown seed such as fleabane and sowthistle.

Weeds along fencelines, paddock edges and non-crop areas of crop paddocks can be controlled by a combination of knockdown herbicides, hay or silage cutting, and/or cultivation. Unlike other activities, timing for fenceline weed control is reasonably flexible with a wide window of opportunity, although control should be carried out before seed is viable. [55]

54 GRDC (2014) Section 7. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-7-Managing-farm-hygiene

55 GRDC (2014) Section 7. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-7-Managing-farm-hygiene

Figure 15: Flaxleaf fleabane along this fence will easily spread into neighbouring fields. (Photo: A. Storrie)

More information

IWM section 4: Tactics

6.12.3 Clean farm machinery and vehicles

Machinery and vehicles are major sources for the introduction of new weeds. Earth-moving equipment, harvesters, balers and slashers are particular problems.

More information

IWM section 4: Tactics

Ensure that machinery and vehicles have been cleaned prior to entry on the farm, or cleaned at a specially designed wash station. Within the farm, harvest from cleanest to dirtiest paddock to minimise the spread of weed seeds. Where breakdowns require in field repair, mark the position with a GPS and diary to check for weed germinations. [56]

6.12.4 Livestock feeding and movement

More information

IWM section 4: Tactics

Weeds can be introduced in stock feed and in livestock over long distances, particularly during droughts. Ensure that you know the source of fodder. New stock or stock returning from agistment need to be kept in a holding paddock for 7 days to enable the bulk of seed in their intestines to be excreted. [57]

6.12.5 Monitor paddocks following flood inundation

Floods and inundation of fields are a common source of new weed infestations through the transport of seeds and vegetative propagules such as stolons, rhizomes and tubers (Figure 17).

Effective monitoring to identify new weed incursions and patches is needed. Hand-roguing a few plants every year can help when weed numbers are very low, even on very large properties. [58]

56 GRDC (2014) Section 7. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-7-Managing-farm-hygiene

57 GRDC (2014) Section 7. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-7-Managing-farm-hygiene

58 GRDC (2014) Section 7. Managing farm hygiene. Integrated weed management manual. Integrated Weed Management Hub, GRDC, http://www.grdc.com.au/Resources/IWMhub/Section-7-Managing-farm-hygiene

More information

[IWM section 4: Tactics](#)

[AWC: Risk of weed movement through vehicles, plant and equipment: results from a Victorian study](#)

[CottonInfo: Come Clean Go Clean](#)

[Farm biosecurity: Grains](#)

[AWC: Seed box survey of field crops in Victoria during 1996 and 1997](#)

[AWC: Weed seed contamination in cereal and pulse crops](#)

GRDC Videos

[GRDC webinar on managing weeds on fencelines](#)

[Weed seed bank destruction—farm hygiene and weed management](#)

Figure 16: This creek line is infested with glyphosate-resistant annual ryegrass and a range of other weeds. During the next flood, these seeds will spread across previously clean paddocks. (Photo: A. Storrie)

SECTION 7

Insect control

More information

[NSW DPI: Winter crop variety sowing guide 2015](#)

[NSW DPI: Insect and mite control in field crops 2103](#)

Few insects pose a threat to oat crops; exceptions are mites when oats are at the seedling stage and aphids for their ability to transmit viruses (Table 1). Other pests are not a major problem in oats but sometimes they build up to an extent that control may be warranted (Table 2). For current chemical control options, refer to Pest Genie or Australian Pesticides and Veterinary Medical Authority (APVMA). [1]

Table 1: Pests that pose a risk to cereal crops [2]

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 expose crops to slugs and snails	Information on pest numbers prior to sowing from soil sampling, trapping and/or baiting will inform management Implementation of integrated slug management strategy (burning stubble, cultivation, baiting) where there is a history of slugs Increased sowing rate to compensate for seedling loss caused by establishment pests	Slugs and snails are rare on sandy soils
Aphids		
Higher rainfall areas where grass weeds are present prior to sowing—higher risk of *Barley yellow dwarf virus* transmission by aphids Wet summer and autumn promoting survival of aphids on weed and volunteer hosts	Wet autumn and spring promote the growth of weed hosts; when weed hosts dry off, aphids move into crops Planting into standing stubble can deter aphids landing Use of seed dressings can reduce levels of virus transmission and delay aphid colonisation Use of synthetic pyrethroids and organophosphates to control establishment pests can kill beneficial insects and increase the likelihood of aphid survival	Low-rainfall areas—lower risk of BYDV infection High beneficial activity (not effective for management of virus transmission)
Armyworm		
Large larvae present when the crop is at late ripening stage	High beneficial insect activity (particularly parasitoids) Rapid crop dry-down	No armyworms present at vegetative and grain-filling stages

[1] DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

[2] NIPI (2014) Winter cereals. IPM guidelines. National Invertebrate Pest Initiative, http://ipmguidelinesforgrains.com.au/crops/winter-cereals/

Table 2: Incidence of pests of winter cereals, where present means occurring but generally not damaging, and damaging means crop susceptible to damage and loss [3]

Note : Snails are also a grain contaminant at harvest

Crop stage:	Emergence	Vegetative	Flowering	Grainfill
Wireworms	Damaging	Present		
Cutworm	Damaging			
Black-headed cockchafer	Damaging	Present		
Earth mites	Damaging	Present		
Slugs, snails	Damaging	Present	Present	Damaging
Brown wheat mite		Damaging		
Aphids	Present	Damaging	Present	Present
Armyworm		Present	Damaging	Damaging
Helicoverpa armigera				Damaging

7.1 Cutworm

Several species of cutworms (*Agrotis* spp.) (Figure 1) attack establishing cereal crops in Queensland and New South Wales. As their name suggests, cutworm larvae sever the stems of young seedlings at or near ground level, causing the collapse of the plant (Table 3).

Damage usually shows as general patchiness or distinct bare areas in a very short time. Controlling weeds in the fallow prior to planting will assist in reducing cutworm population and reduce crop damage. This should be done at least 21–28 days prior to sowing. Chemical control may be warranted if larval numbers exceed one larva per m^2 in emerging crops.

The best time to monitor is late afternoon–evenings when larvae feed. During the day, scratch away soil around damaged plants to find larvae sheltering in the soil or at the interface between the wet and the dry soil. For more information read how to recognise and monitor for soil insects in Insect pest management in winter cereals. [4]

Figure 1: Cutworm (Photo: DAF Qld)

[3] NIPI (2014) Winter cereals. IPM guidelines. National Invertebrate Pest Initiative, http://ipmguidelinesforgrains.com.au/crops/winter-cereals/

[4] DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

Table 3: Cutworm description and management summary [5]

Scientific name	*Agrotis* spp.
Description	Larvae are up to 50 mm long, hairless with dark heads and usually darkish coloured bodies, often with longitudinal lines and/or dark spots. Larvae curl up and remain motionless if picked up. Moths are a dull brown-black colour
Similar species	May be confused with armyworms and *Helicoverpa* larvae
Crops attacked	All field crops. Crops are at most risk during seedling and early vegetative stages
Damage	Young caterpillars climb plants and skeletonise the leaves or eat small holes. Older larvae may also climb to browse or cut off leaves, but commonly cut through stems at ground level and feed on the top growth of felled plants. Caterpillars that are almost fully grown often remain underground and chew into plants at or below ground level. They usually feed in the late afternoon or at night. By day they hide under debris or in the soil
Monitoring and action level	Inspect crop twice weekly in seedling and early vegetative stage. Larvae feed late afternoons and evenings. Chemical control is warranted when there is a rapidly increasing area or proportion of crop damage
Life cycle	Usually a single generation during early vegetative stages. Moths prefer to lay their eggs in soil in lightly vegetated (e.g. a weedy fallow) or bare areas. Early autumn egg-laying results in most damage to young cereals. Larvae hatch and feed on host plants right through to maturity. Mature larvae pupate in the soil. Under favourable conditions, the duration from egg-lay to adult emergence is 8–11 weeks, depending on the species
Control	Chemical control: Insecticide application is cost-effective. The whole crop may not need to be sprayed if distribution is patchy; spot spraying may suffice. See Pest Genie or APVMA for current control options. Cultural control: Control weeds 3–4 weeks prior to sowing. Natural enemies: Cutworms are attacked by a number of predators, parasites and diseases
Pest status	Minor, widespread, irregular

7.2 Aphids

Aphids are usually regarded as a minor pest of winter cereals, but in some seasons, they can build up to very high densities. Four species of aphid can infest winter cereals: oat aphid, corn aphid, rose-grain aphid, rice root aphid (which exists in the northern grain region, but does not cause as much damage to cereals).

Aphids can impair growth in the early stages of the crop, and prolonged infestations can reduce tillering and result in earlier leaf senescence. Infestations during booting to milky dough stage, particularly where aphids are colonising the flag leaf, stem and ear, result in yield loss, and aphid infestations during grainfill may result in low-protein grain. Because aphids may compete with the crop for nitrogen (N), crops grown with marginal levels of N can be more susceptible to the impact of an aphid infestation..

In oats, aphids can spread *Barley yellow dwarf virus* (BYDV). In virus-prone areas, use resistant plant varieties and insecticidal seed dressing to minimise losses due to BYDV.

More information

DAF Qld: Oat aphid, wheat aphid

GRDC: Ute Guide—oat aphid

DAFWA: Oats: insect pests

7.2.1 Thresholds for control

Inspect for aphids throughout the growing season by monitoring leaves, stems and heads as well as exposed roots. Choose six, widely spaced positions in the crop, and at each position examine five consecutive plants in a row. Research is under way into damage thresholds and control options for cereal aphids. Some research indicates that aphid infestations can reduce yield by ~10% on average. Current national thresholds suggest that control is warranted when there are >10–20 aphids on 50% of the tillers.

The decision to control aphids on winter cereals depends on the size of the aphid population and the duration and timing of the infestation. Controlling aphids during early crop development generally results in a recovery of the rate of root and shoot

[5] DAF Qld (2010) Cutworm. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects/cutworm

development, but there can be a delay. Aphids are more readily controlled in seedling and pre-tillering crops, which are less bulky than post-tillering crops. Corn aphids in the terminal leaf tend to disappear as crops come into head, and other species usually decline in abundance about this time as natural enemy populations build up. The rice root aphid feeds belowground and cannot be controlled effectively by non-systemic foliar treatments. [6]

No firm economic thresholds exist (taking into account current costs of control and crop value), but there are thresholds suggested from work in Western Australia and by the Northern Grower Alliance (NGA).

The Western Australian threshold, based on checking crops regularly from late tillering, is to consider control if the aphid population exceeds 15 aphids/tiller on 50% of tillers.

The NGA work shows an economic (yield) benefit at some sites from controlling aphids early (either seed treatments or at the early tillering stage), using a threshold of 10 aphids/tiller.

In Queensland, several field and glasshouse trials have been conducted over the four seasons, but entomologists have not obtained consistent yield loss in trials that tested a range of aphid infestations at different stages of crop development. [7]

Recently, the NGA has been involved in a large number of trials to improve industry understanding of the impact of aphids on winter cereal yields and the costs and benefits of different management approaches.

Key findings include:

- A threshold of ~10–15 aphids/tiller appears a suitable commercial trigger for aphid management in winter cereals.
- Monitor for early populations of oat aphids by pulling up plants and examining crown and sub-crown regions.
- However, consider foliar sprays only when most oat aphids have moved aboveground into the lower canopy.
- Best results from foliar sprays are obtained when the aphid population is close to threshold and increasing.
- Beneficial insects can provide effective aphid control in winter cereals. Consider beneficial presence or activity before making spray decisions. Look for aphids that have been killed or 'mummified' by predators.
- Consider aphid-active seed treatments for use in oats or areas with consistently higher aphid pressure. [8]

7.2.2 Seed dressings

Prophylactic seed dressings may be effective in delaying the build-up of aphid populations in a crop, but because aphids are sporadic (not occurring every season), it can be difficult to decide whether a seed dressing is warranted. A locally wet summer and autumn is generally a precursor to an aphid outbreak, because of the abundance of alternative hosts to breed on. [9] The use of such seed dressings can also reduce the spread of diseases such as BYDV.

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6 DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

7 M Miles (2012) Making a decision about control of aphids in winter cereals. *The Beatsheet*, Queensland Government, http://thebeatsheet.com.au/winter-cereals/making-a-decision-about-control-of-aphids-in-winter-cereals/

8 NGA (2011) Aphid management in winter cereals 2009–2010. Results in a Nutshell. Northern Grower Alliance, http://www.nga.org.au/module/documents/download/79

9 DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

Seed dressings are available that are suppress aphid feeding and reduce the spread of BYDV. They contain imidacloprid alone (e.g. Gaucho®, Senator®) or with a second active ingredient such as tebuconazole (Hombre®), triadimenol (Zorro®) or flutriafol (Veteran®, Arrow®). [10]

7.2.3 Natural enemies

Delay any planned chemical control if rain is forecast, and check again after rain; intense rainfall can reduce aphid infestations by dislodging aphids from the plants. Foliar insecticides registered for aphid control are generally broad-spectrum, meaning that they kill natural enemies (beneficial insects such as ladybird beetles and larvae, hover fly larvae, lacewing larvae or parasitic wasps; Figure 2) as well as aphids. Preserving natural enemies is important in managing aphid populations in the long term. Natural enemies can exert effective control on small to moderate aphid infestations. Large populations of aphid can also be controlled, but often not until the crop is maturing, which may be too late to prevent impact on yield. Natural enemies can also be effective in suppressing aphids that survive post-treatment, preventing the need for subsequent treatments. [11]

Figure 2: Preserving natural enemies is important in managing aphid populations in the long term. (Photo: DAF Qld)

[10] P Matthews, D McCaffery, L Jenkins (2015) Winter crop variety sowing guide 2015. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

[11] DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

7.2.4 Rose-grain aphid (*Metopolophium dirhodum*)

Rose-grain aphids are one of the three main aphids that attack cereal crops in the Northern Region (Figure 3, Table 4). They are also a vector for the spread of BYDV.

Figure 3: Rose-grain aphid. (Photo: DAF Qld)

Table 4: Rose-grain aphid management summary [12]

Scientific name	*Metopolophium dirhodum*
Description	Adults are 3 mm long, green to yellow-green with long and pale siphunculi (tube-like projections on either side at the rear of the body) and may have wings. There is a dark green stripe down the middle of the back. Antennae reach beyond the base of the siphunculi. Nymphs are similar but smaller in size
Similar species	Because of its distinctive colour, it is unlikely to be confused with other aphids
Distribution	An introduced species that has been recorded in New South Wales, Queensland, South Australia, Tasmania and Victoria
Crops attacked	Wheat, barley, triticale, oats
Life cycle	Undergoes many generations during the growing season; winged and non-winged forms occur
Damage	Adults and nymphs are sap-suckers. Under heavy infestations, plant may turn yellow and appear unthrifty. Can spread BYDV in wheat and barley
Monitoring and action level	Can affect any crop stage; assess the potential for direct-feeding damage in late winter. Estimate the number of aphids per tiller. Aphids are unlikely to cause economic damage to cereal crops expected to yield <3 t/ha
Control	Chemical control: Apply a foliar insecticide in late winter or spring to avoid damage to tillers. To prevent losses from BYDV in virus-prone areas, control aphids early in the cropping year. For current chemical control options see Pest Genie or APVMA Cultural control: There are no known effective cultural control methods for this aphid
Natural enemies	Predation by hoverflies, lacewings and ladybird beetles, parasitism by wasps and heavy rainfall can reduce aphid populations

12 DAF Qld (2011) Rose-grain aphid. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/rose-grain-aphid

7.2.5 Oat or wheat aphid (*Rhopalosiphum padi*)

Oat or wheat aphid is one of the most common aphid-infesting winter cereals (Figure 4, Table 5). Typically, this species colonises the base and lower portions of the plant. [13]

Figure 4: Oat or wheat aphid. (Photo: DAF Qld)

Table 5: Oat or wheat aphid management summary [14]

Scientific name	*Rhopalosiphum padi*
Description	Adults are 2 mm long, olive-green to black with a red rust patch at the rear end and may have wings. Antennae extend to half the body length. Nymphs are similar but smaller. Wheat and oat aphids are very similar to corn aphids
Distribution	An introduced species found in all states of Australia
Crops attacked	Barley, wheat and oats
Life cycle	A species that produces many generations through the growing season. Winged and non-winged forms occur
Damage	Aphids feed directly on stems, leaves and heads, and in high densities cause yield losses and plants may appear generally unthrifty. This type of damage is rare throughout the grainbelt. Aphids can spread BYDV
Monitoring and action level	Aphids can affect any crop stage but are unlikely to cause economic damage to cereal crops expected to yield <2 t/ha. Consider treatment if there are 10–20+ aphids on 50% of tillers
Control	Chemical control: Apply a foliar insecticide in late winter or spring to avoid direct damage to tillers and heads. To prevent losses from BYDV in virus-prone areas, control aphids early in the cropping year. Prevent infestation by applying a seed dressing to early-sown crops and a foliar insecticide in high-pressure years if necessary (predator-friendly). For current chemical control options, see Pest Genie or APVMA Cultural control: Controlling the green bridge, i.e. controlling weeds over the summer fallow, is an effective control measure to prevent aphid survival into the next season
Host-plant resistance	In virus-prone areas, use resistant plant varieties to minimise losses due to BYDV
Natural enemies	Predation by hoverflies, lacewings and ladybeetles and parasitism by wasps can reduce aphid populations, but this does not happen in every season. Heavy rain may reduce aphid populations significantly

13 DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

14 DAF Qld (2011) Oat aphid, wheat aphid. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/oat-aphid,-wheat-aphid

7.2.6 Corn aphid (*Rhopalosiphum maidis*)

Corn aphid (Figure 5, Table 6) is another a common species found in sorghum, maize and barley but occasionally in oats, wheat and triticale. They generally colonise the upper parts of the plant, particularly the rolled up terminal leaf. [15] Corn aphids can spread BYDV.

Figure 5: Corn aphid. (Photo: DAF Qld)

Table 6: Corn aphid management summary [16]

Scientific name	*Rhopalosiphum maidis*
Description	Up to 2 mm long, light to dark olive-green with a purple area at the base of small tube-like projections at the rear of the body. Adults are generally wingless. Antennae extend to about a third of body length. Nymphs are similar, but smaller in size
Similar species	Other species of aphids
Distribution	An introduced species, probably Asiatic in origin, found in all states of Australia
Crops attacked	Sorghum, maize, winter cereals and many grasses Life cycle on sorghum: Corn aphids breed throughout summer on sorghum with a life cycle of about 7 days. Up to 13 generations on a sorghum crop, and 30 generations/year Life cycle on cereals: A parthenogenetic species that undergoes many generations through the growing season. Both winged and non-winged forms occur

15 DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

16 DAF Qld (2010) Corn aphid. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/aphid-overview/corn-aphid

Damage	In cereal: Aphids feed on stems, leaves and heads, and in high densities cause yield losses. However, this type of damage is uncommon throughout the cereal belt. Risk period for cereals: Most prevalent on cereals in late winter and early spring. High numbers often occur in years when an early break in the season and mild weather in autumn and early winter provide favourable conditions for colonisation and multiplication
Monitoring	Estimate percentage of plants infested and percentage of leaf area covered by aphids
Action level	Aphids are unlikely to cause economic damage to cereal crops expected to yield <3 t/ha. To avoid damage by direct feeding, consider treatment if there are 10–20+ aphids on 50% of the tillers
Chemical control	Chemical control is cost-effective. See Pest Genie or APVMA for current control options Conservation of natural enemies: A range of parasitoids and predators will help to reduce aphid populations. Predators of aphids include: ladybird larvae, damsel bugs, big-eyed bugs and the larvae of green lacewings and hoverflies. Wasp parasitoids mummify and kill aphids
Host plant resistance	In sorghum, hybrids with open heads are less infested than tight-headed hybrids

7.3 Armyworm

Armyworms (Figure 6) are the caterpillar stage of certain moths, and can occur in large numbers, especially after good rain following a dry period. Larvae shelter in the throats of plants or in the soil and emerge after sunset to feed on the leaves of all winter cereals, particularly barley and oats, generally during September and October.

Leafy cereal plants can tolerate considerable feeding, and control in the vegetative stage is seldom warranted unless large numbers of armyworms are distributed throughout the crop or they are moving in a 'front', generally from an adjacent grass pasture, destroying young seedlings or completely stripping older plants of leaf. The most serious damage occurs when larvae feed on the upper flag leaf and stem node as the crop matures, or in oats when the older larvae start feeding on the green stem just below the head as the crop matures, causing the stem to snap and the head of forming grain to die.

More information

Agriculture Victoria: Armyworms

Figure 6: Armyworm caterpillar. (Photo: DAF Qld)

The most common species in the Northern Region are common and northern armyworms (*Leucania convecta* and *L. separata*), and lawn armyworm (*Spodoptera mauritia*). Infestations are evident by scalloping on margins of leaves caused by feeding of the older larvae. Larvae target the stem node as the leaves become dry and unpalatable, and the stem is often the last part of the plant to dry. One large larva can sever up to seven heads of cereal a day. One larva per m^2 can cause a grain loss of 70 kg/ha.day (Table 7). Larvae take ~8–10 days to develop through the final, most damaging instars, with crops susceptible to maximum damage for this period (Table 8).

Check for larvae on the plant and in the soil litter under the plant. The best time to do this is late in the day when armyworms are most active. Alternatively, look around the base of damaged plants where the larvae may be sheltering in the soil during the day. Using a sweep net (or swing a bucket), check a number of sites throughout the paddock. Sweep sampling is particularly useful early in an infestation when larvae are small and actively feeding in the canopy. One full sweep with a net samples the equivalent of 1 m^2 of crop.

Table 7: Value of yield loss incurred by armyworm larvae, based on approximate values for wheat and an estimated loss with one larva per m^2 of 70 kg/ha

Considering these values and the relatively low cost of controlling armyworm, spraying is warranted on populations in ripening crops with more than one large larva per m^2

Value of grain (AU$/t)	Value of yield loss ($) per ha per day	
	One larva per m^2	Two larvae per m^2
$140	$9.80	$19.60
$160	$11.20	$22.40
$180	$12.60	$25.20
$200	$14.00	$28.00
$220	$15.40	$30.80
$250	$17.50	$35.00
$300	$21.00	$42.00
$350	$24.50	$49.00
$400	$28.00	$56.00

Early recognition of the problem is vital, because cereal crops can be almost destroyed by armyworm in just a few days. Although large larvae do the head lopping, controlling smaller larvae that are still leaf-feeding may be more achievable. Prior to chemical intervention, consider how quickly the larvae will reach damaging size, and the development stage of the crops. Small larvae take 8–10 days to reach a size capable of head-lopping, so if small larvae are found in crops nearing full maturity–harvest, spray may not be needed. On the other hand, small larvae in late crops that are still green and at early seed-fill may reach a damaging size in time to reduce crop yield significantly.

Control is warranted if the armyworm population distributed throughout the crop is likely to cause the loss of 7–15 heads/m^2. Many chemicals will control armyworms. However, their effectiveness often depends on good penetration into the crop to achieve contact with the caterpillars. Control may be more difficult in high-yielding, thick-canopied crops where uniform coverage is not possible, particularly when larvae are resting under soil at the base of plants. Larvae are most active at night; therefore, spraying in the afternoon or evening may produce the best results. If applying sprays close to harvest, be aware of relevant withholding periods.

Biological control agents may be important in some years. These include parasitic flies and wasps, predatory beetles and diseases. Helicoverpa NPV (nuclear polyhedrosis virus) is not effective against armyworm. [17]

[17] DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

Table 8: Armyworm management summary [18,19]

Scientific name	*Leucania convecta*, common armyworm; *L. separata*, northern armyworm; *Spodoptera mauritia, lawn armyworm*
Description	Common armyworm: First-instar larvae are about 1 mm long. From the second instar, stripes develop along the top and sides of the larva and become more distinct as the larva grows. Crowded larvae are usually darker than uncrowded. Mature larvae grow up to 40 mm in length and have three characteristic pale stripes on the head, collar (segment behind the head) and tail segment. They are smooth-bodied with no distinct hairs. The body also has lateral stripes. The forewings of the moth have a wingspan of about 40 mm and are fawn or buff Northern armyworm: Larvae and adults are very similar to the common armyworm Lawn armyworm: Moths are mainly brown with complex pattern of creamy and grey markings
Similar species	Adults of the common and northern armyworms may be confused. Genitalia dissections by a specialist are required to separate the species. The larval stages likely to be encountered in cereals are all similar in appearance
Distribution	Common armyworm: Native Australian species, recorded in New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia Northern armyworm: Throughout South-East Asia, New Zealand and in Australia, where it occurs in all states except Tasmania Lawn armyworm: Africa, Asia Pacific Islands and Australia throughout Queensland but more commonly in coastal and subcoastal areas
Crops attacked	Common armyworm: Damages barley, oats, wheat, native pasture grasses and perennial grass seed crops Northern armyworm: In Queensland, recorded as damaging sorghum, maize, barley, wheat and rice Lawn armyworm: Grasses, barley, oats, wheat
Life cycle	Common armyworms have three generations per year. The winter and spring generations damage cereals. Moths fly into cereal crops and lay their eggs in the folds of dried or drying leaves on grasses or cereals. Females lay up to 1000 eggs in irregularly shaped masses, cemented in tight folds of foliage. Eggs hatch in as little as 3–4 days after laying, and young larvae, with the assistance of wind, disperse through the crop on fine silken threads. The larvae feed on leaves and stems. Larvae usually develop through six instars, sometimes seven. Indicative development times at constant temperature are: egg-laying to hatch, 7 days at 20°C and 2.5 days at 30°C; larval stages (including pre-pupal stage) 34.2 days at 20°C and 17.2 days at 30°C. Larvae pupate in the soil. Pupal stage lasts 20.1 days at 20°C and 10.1 days at 30°C. Development time from neonate to adult emergence is 61 days at 20°C and 41 days at 30°C (Smith 1984) Northern armyworm—similar to common armyworm Lawn armyworm: Eggs are laid as clusters covered with fine scales onto the under-surface of non-host vegetation. Eggs hatch in 2–10 days depending on temperature, and the seven or eight larval instars are completed after 14–35 days; adults emerge from pupae after a further 7–14 days. Adults live 7–14 weeks and the species may complete two or three generations during summer and spring

18 DAF Qld (2010) Common, northern and sugarcane armyworms. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/armyworm-overview/common,-northern-and-sugarcane-armyworms

19 DAF Qld (2010) Lawn armyworm in pastures, lawns and field crops. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/armyworm-overview/lawn-armyworm

Risk period and damage	Risk period: The greatest risk to cereals is spring. Moth flights occur in September and October, and the later stage larvae damage cereals often in the weeks prior to harvest. The mature larval stages of the winter generation will sometimes march in cereal crops in late winter and cause serious damage to crops, particularly on the edges of paddocks. Crops directly seeded into standing stubbles are susceptible to severe defoliation during the vegetative stage as the winter generation matures Damage: There are two distinct periods for economic damage. The first, defoliation during early vegetative development, is less common than the second through ripening. Ripening barley is most susceptible to armyworm damage because mature larvae feed on the green tissue just below the head, thereby severing the head. One larva can lop many heads very quickly causing large grain losses. Oats are also damaged but the less compact seed head means less damage and grain loss
Monitoring and action level	Large numbers of armyworm moths are attracted to farm lights on warm nights in September and October. This provides the first warning of potential problems in cereals. Armyworm larvae are difficult to find in cereals crops because they hide at the base of plants or under clods of soil during the day. Search at the base of plants and under clods of soil to estimate the number of larvae per m^2. Presence of green-yellow, pellet-shaped droppings of the larvae on the ground is usually a reliable sign of larvae. Monitor for larvae at dusk with a sweep net; sweep netting during the day can be unreliable Action level: Two larvae per m^2 for barley. Other cereals are likely to tolerate slightly higher numbers
Control	Chemical control: A range of insecticides is registered for armyworm control in cereals. Insecticides should target larvae 10–20 mm long. Larvae >20 mm long can be difficult to kill and may require higher rates of insecticide. If possible, spray late in the day because larvae are active at night. See Pest Genie or APVMA for current control options. Cultural control: Windrowed or swathed crops dry out rapidly, rendering them unattractive to the feeding of armyworm larvae. They are also less susceptible to wind damage (head shattering)
Natural enemies	Armyworm larvae are attacked by a number of parasitoids that may be important in reducing the intensity of outbreaks. When armyworms are in numbers likely to cause damage, parasitoids are unlikely to give timely control. Predators include green carab beetles, populations of which increase dramatically in inland Australia in response to abundant cutworm larvae induced by favourable seasons. Other predators include the predatory shield bugs and perhaps common brown earwigs. Fungal diseases are recorded as causing mortality of armyworm

7.4 Mites

7.4.1 Blue oat mite (*Penthaleus* spp.)

Blue oat mites (Figure 7, Table 9) are important pests of seedling winter cereals, with a preference for oat crops. They are generally restricted to cooler grain-growing regions (southern Queensland through eastern New South Wales, Victoria, South Australia and southern Western Australia). There are three pest species of blue oat mite in Australia (*Penthaleus major*, *P. falcatus*, *P. tectus*). [20]

The presence of a small red spot on their back is the easiest way to distinguish them from red legged earth mites. They are the predominant species from Dubbo to the north, whereas redlegged earth mites (RLEM) prefer more southern climes.

Figure 7: Blue oat mite. (Photo: DAF Qld)

[20] Agriculture Victoria (2007) Blue oat mite. DEDJTR Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/blue-oat-mite

Adults and nymph mites pierce and suck leaves, resulting in silvering of the leaf tips. Feeding causes a fine mottling of the leaves, similar to the effects of drought. Heavily infested crops may have a bronzed appearance, and severe infestations cause leaf tips to wither and can lead to seedling death. Damage is most likely during dry seasons when mites in large numbers heighten moisture stress; control may be warranted in this situation.

Check from planting to early vegetative stage, particularly in dry seasons, monitoring a number of sites throughout the field. Blue oat mites are most easily seen in the cooler part of the day, or if it is cloudy. They shelter on the soil surface when conditions are warm and sunny. If pale-green or greyish silver irregular patches appear in the crop, check for the presence of blue oat mite at the leaf base.

Where warranted, foliar application of registered insecticide may be cost-effective. Check the most recent research to determine the likely susceptibility of blue oat mite to the available registered products. Cultural control methods can contribute to reduction in the size of the autumn mite population (e.g. cultivation, burning, controlling weed hosts in fallow, grazing and maintenance of predator populations). Because eggs laid in the soil hibernate throughout winter, populations of the mite can build up over a number of years and cause severe damage if crop rotation is not practiced.

Predators of blue oat mites include spiders, ants, predatory beetles and the predatory *Anystis* mite and snout mite. Blue oat mites are also susceptible to infection by a fungal pathogen (*Neozygites acaracida*), particularly in wet seasons. [21]

More information

NSW DPI: Insect and mite control in field crops 2013 (p. 28)

Agriculture Victoria: Blue oat mite

Table 9: Management summary of blue oat mite [22]

Scientific name	*Penthaleus spp.*
Description	Adults are 1 mm long and have eight legs. Adults and nymphs have a purplish blue, rounded body with red legs. They move quickly when disturbed. The presence of a small red area on the back distinguishes it from the RLEM
Similar species	Brown wheat mite, RLEM
Crops attacked	Mainly a pest of cereals and grass pastures, but will feed on pasture legumes and many weeds
Damage	Adults and nymphs pierce and suck on leaves resulting in silvering of the leaf tips in cereals. When heavy infestations occur, the leaf tip withers and the seedling can die
Monitor	Check from planting to early vegetative stage, particularly in dry seasons. Most easily seen in the late afternoon when they begin feeding on the leaves
Control	Foliar applications of insecticides may be cost-effective if applied within 14–21 days of emergence in autumn. The use of control tactics solely in spring will not prevent the carryover of eggs into the following autumn. For current chemical control options see Pest Genie or APVMA
Natural enemies	Thrips and ladybirds

21 DAF Qld (2012) Insect pest management in winter cereals. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-winter-cereals

22 DAF Qld (2010) Blue oat mite. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/mites-overview/blue-oat-mite

7.4.2 Redlegged earth mites (*Halotydeus destructor)*

Redlegged earth mites (Figure 8) are one of the more prominent pests of oats in the southern parts of the Northern Region. They prefer oats to other cereals and they can often be found first on the wild oats plants in a wheat crop. Characteristics and management of RLEM are summarised in Table 10.

Figure 8: Adult redlegged earth mite. (Photo: **Cesar***)*

Table 10: Management summary of redlegged earth mite

Scientific name	*Halotydeus destructor*
Description	Adults are 1 mm long and have eight legs. Adults and nymphs have a black, somewhat flattened body and red legs
Similar species	Similar in appearance to blue oat mite; however, blue oat mite can be distinguished by a small oval red area in the middle of the back
Distribution	Originated in South Africa, now found in New Zealand and Australia. The redlegged earth mite is widely distributed in winter-rainfall-dominant regions of southern Australia
Pest status	Major, widespread, regular, in southern Australia
Crops attacked	Damages all field crops and pastures, especially at seedling stage. A major pest of legume pastures and canola
Damage	Adults and nymphs feeding cause a silver or white discoloration of leaves and distortion of leaf shape. Affected seedlings can die. Seedlings can be killed before emergence. There is also reduced production and quality of older green plants during the growing season and reduced seed yield of legumes in spring
Risk period	Autumn to spring, especially at germination
Life cycle	On winter-rainfall pastures: Active in the cool, wet months from May to November. They hatch in autumn at the break of the season, from over-summering eggs that have been in a state of arrested development (diapause) since the end of the previous spring. Hatching is triggered by a significant rainfall event combined with a period of 7–10 days in which the mean daily maximum temperature is <21°C Eggs hatch into six-legged larvae and then develop through three nymphal stages into adults. Nymphs and adults have eight legs. During winter, the redlegged earth mite passes through three generations on average, each lasting about 8 weeks. When conditions are favourable, numbers can increase rapidly, with peaks in autumn and/or spring
Monitoring	Monitor pastures regularly from the time of first emergence of seedlings. Approach quietly; mites will disperse quickly if disturbed. If mites are not found on the plants, look carefully at the soil surface. A hand-lens will be required to detect newly hatched larvae and young nymphs
Action level	Any sign of mite activity or damage at germination warrants control. At other times of the season, feeding damage to >20% of the leaf area may warrant control

Control	Chemical control: Treating seed with systemic insecticide before sowing pastures protects seedlings from attack. Chemical sprays do not kill mite eggs, so it is important to time sprays when most mites have emerged. Spraying should be timed for autumn or spring. In autumn, chemicals should be applied after the break of season, and after all of the over-summering eggs have hatched but before adult mites start laying eggs. For current chemical control options see APVMA Cultural control: Heavy grazing in winter and spring reduces mite populations. Control of broadleaf weeds in summer can reduce mite populations in autumn Natural enemies: A predatory mite, *Anystis wallacei*, was imported from France to Australia in 1965 for biological control and has established at some sites where it has caused significant mortality of redlegged earth mites. Its effectiveness is limited by its slow dispersal

Cold, wet conditions are required for this species to hatch. Recent research by Garry McDonald suggests that the process of egg development in autumn requires at least 5 mm of rain accumulated over a period of five consecutive days or less, followed by 10 days in which average daily temperature remains <16°C. This minimises the chance of eggs hatching (and perishing) in early autumn following a false break. [23]

A few chemicals are registered for the control of RLEM but their effectiveness is in question. Heavy reliance on only three registered chemical groups to control RLEM—neonicotinoids as a seed dressing, and synthetic pyrethroids (SPs) and organophosphates (OPs) as foliar insecticides—has quickly selected for resistance. Resistance to SPs is confirmed in large populations of RLEM across the Western Australian (WA) grainbelt, and some populations there have resistance to OPs. [24] Such resistance is therefore likely to become commonplace in the eastern states.

Although control measures for RLEM are largely based on chemicals, non-chemical control options include:

- growing crops that do not support large populations of mites (e.g. pulses) before susceptible crops such as canola or oats
- grazing pasture paddocks heavily through spring in the year prior to sowing susceptible crops (e.g. canola)
- decreasing weeds that will host mite populations during the crop phase and around fence lines [25]

It is important to identify RLEM correctly from other mite species and for their resistance status, so that the appropriate management can be determined. This may include non-chemical controls or spraying or a decision not to apply an insecticide.

Resistance-testing of RLEM is available through a GRDC-funded project led by the University of Melbourne, in collaboration with **cesar**, the Department of Agriculture and Food WA, CSIRO and the University of WA. In 2016, this service is available to all grain growers across Australia. For more information, contact:

Dr Paul Umina (**cesar** and the University of Melbourne)
03 9349 4723, pumina@cesaraustralia.com

More information

NSW DPI: Insect and mite control in field crops 2013

23 **cesar** (2014) Redlegged earth mites. PestFacts south-eastern. **cesar**, http://cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2015/pestfacts-issue-no-1-8th-may-2014/redlegged-earth-mites/

24 A Lawson (2015) Test your mites for resistance. Ground Cover Issue 117, GRDC, https://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Test-your-mites-for-resistance

25 A Lawson (2015) Test your mites for resistance. Ground Cover Issue 117, GRDC, https://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Test-your-mites-for-resistance

7.4.3 *Balaustium* mites (*Balaustium medicagoense*)

The *Balaustium* mite (Figure 9, Table 11) is commonly confused with *Bryobia* mite, and sometimes with blue oat mite and RLEM. However, adult *Balaustium* mites are generally twice as large as other adult mites.

Figure 9: Balaustium mite. (Photo: **cesar***)*

Table 11: Management summary of Balaustium mite

Scientific name	*Balaustium medicagoense*
Description	Adults are 2 mm long and have eight red-orange legs and a rounded red-brown body. Newly hatched nymphs are bright orange with six legs and are only 0.2 mm long. Adults are covered with short, stout hairs. They are slow moving and have distinctive, pad-like structures on their forelegs
Similar species	*Commonly confused with Bryobia* mite, and sometimes with blue oat mite and redlegged earth mite; however, *Balaustium mite is bigger*
Crops attacked	Canola, lupins and cereals are the most susceptible crops, particularly at the seedling stage. Some broadleaf weeds are alternative hosts
Damage	Typical damage to cereals, grasses and pulses is silvering or whitening of the attacked foliage, similar to damage caused by RLEM and blue oat mites. However, *Balaustium* mites tend to attack the leaf edges and tips of plants. Adult mites are likely to be responsible for the majority of feeding damage to plants by this species. *Balaustium* mites feed on plants by using their adapted mouthparts to probe leaf tissue and suck up sap. In most situations, they cause little damage; however, when numbers are high and plants are already stressed from other environmental conditions, significant damage to crops can occur
Monitor	Carefully inspect susceptible pastures and crops from autumn to spring for the presence of mites and evidence of damage. It is especially important to inspect crops regularly in the first 3–5 weeks after sowing Crops sown into paddocks that were in pasture the previous year should be regularly inspected. Weeds present in paddocks prior to cropping should also be checked for the presence and abundance of Balaustium mites. Mites are best detected feeding on the leaves, especially on or near the tips, during the warmest part of the day. They are difficult to find when conditions are cold and/or wet
Control	*Balaustium* mites have a high natural tolerance to chemicals and they will typically survive pesticide applications aimed at other mite pests. [26] Very few effective biological control options. Early control of summer and autumn weeds within and around paddocks, especially cape weed and grasses, will help to control populations

[26] GRDC (2012) Crop mites. Back Pocket Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2012/06/GRDC-Crop-Mites-Back-Pocket-Guide

Balaustium mites are widespread throughout most agricultural regions in southern Australia with a Mediterranean-type climate. They are found in Victoria, South Australia, and in the east and south of New South Wales (Figure 10).

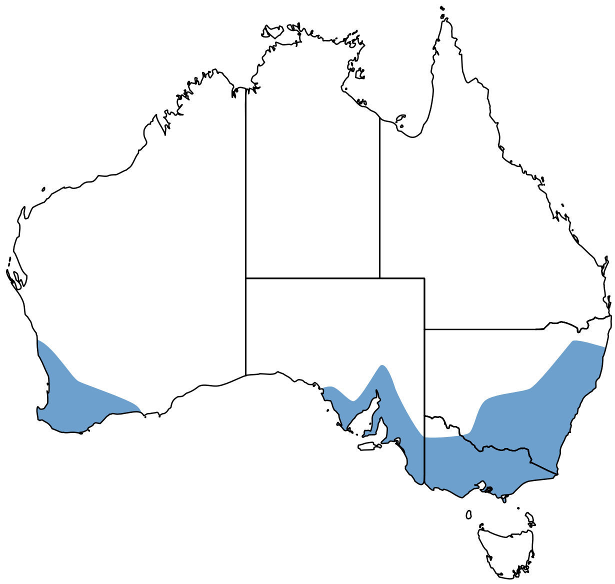

Figure 10: Distribution of Balaustium mite in southern Australia. (Source: Agriculture Victoria)

Little is known about the biology of *Balaustium* mites. *They* usually have two generations per season and are unlikely to require cold temperatures to stimulate egg hatching in the way that other species do.

Similar to other pest mites, long-range dispersal is thought to occur via the movement of eggs in soil adhering to livestock and farm machinery or through transportation of plant material. Movement may also occur if oversummering eggs are moved by summer winds.

Balaustium mites are unusual in that they not only feed on plants but also prey upon other small invertebrates. They have been reported to feed on several different groups, including various Collembola species and other mites. *Balaustium* mites were originally thought to be a beneficial predator, with some reports suggesting that they provided localised control of redlegged earth mites. Only recently have *Balaustium* mites been confirmed to feed on plant material.

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.

More information

[DAFWA: Oats: insect pests]

One of the most effective methods to sample mites is by using a D-Vac, which is based on the vacuum principle, much like a domestic vacuum cleaner. Typically, a standard, petrol-powered garden blower–vacuum machine is used. A sieve is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface. [27]

7.4.4 *Bryobia* mites

Bryobia mites (also referred to as clover mites) (Figure 11, Table 12) are smaller than other commonly occurring pest mites. The egg of the *Bryobia* mite is minute, globular

27 Agriculture Victoria (2010) *Balaustium* mite. AG1413. DEDJTR Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/balaustium-mite

and red. It can be distinguished from European red mite eggs by its smooth appearance and lack of a spike. The nymph looks like the adult but is smaller. [28]

Many species of *Bryobia* mites are found in grain crops in Australia. They are found in high numbers in the warmer months from spring through to autumn. [29]

Figure 11: Adult Bryobia mite. (Photo: **cesar***)*

Table 12: Management summary of Bryobia mite

Scientific name	*Bryobia spp.*
Description	Smaller than other mites, reaching ~0.75 mm in length as adults. They have an oval, flattened dorsal body that is dark grey, pale orange or olive, with have eight pale-orange legs. The front pair of legs is much larger, about 1.5 times their body length. Nymphs are small with bright-red bodies and pale legs [30]
Similar species	Brown wheat mite, *Balaustium* mite, RLEM
Crops attacked	*Bryobia* mites prefer broadleaf plants such as canola, lupins, vetch, lucerne and clover, but they will also attack cereals.
Damage	Feed on upper surfaces of leaves and cotyledons by piercing and sucking leaf material, resulting in distinctive trails of whitish-grey spots on leaves
Monitor	Crops that follow clover-dominant pastures are most at risk, and should be monitored carefully
Control	No known biological control options. Early control of summer and autumn weeds within and around paddocks, especially broadleaf weeds such as cape weed and clovers, will help to control populations Several pesticides are registered for use on Bryobia mites; higher rates are usually required than for RLEM and blue oat mites. Bryobia mites have a natural tolerance to several chemicals [31]

More information

DAFWA: Oats: insect pests

7.5 Wireworms and false wireworms

Importance

Wireworms and false wireworms are common, soil-inhabiting pests of newly sown winter and summer crops. Wireworms are the larvae of several species of Australian native beetles, commonly called 'click beetles', from the family Elateridae. False wireworms are also the larval form of adult beetles, some of which are known as 'pie-

[28] Agriculture Victoria (2000) The *Bryobia* mite and the pear-leaf blister mite. DEDJTR Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/the-bryobia-mite-and-the-pear-leaf-blister-mite

[29] GRDC (2012) Crop mites. Back Pocket Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2012/06/GRDC-Crop-Mites-Back-Pocket-Guide

[30] GRDC (2012) Crop mites. Back Pocket Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2012/06/GRDC-Crop-Mites-Back-Pocket-Guide

[31] GRDC (2012) Crop mites. Back Pocket Guide. GRDC, http://www.grdc.com.au/Resources/Publications/2012/06/GRDC-Crop-Mites-Back-Pocket-Guide

dish beetles', which belong to another family (Tenebrionidae) and have distinctively different forms and behaviour.

Both groups inhabit native grassland and improved pastures, where they cause little damage. However, cultivation and fallow decimate their food supply, and hence, any new seedlings that grow may be attacked and sometimes destroyed. They attack the seedlings at pre- and post-emergence of all oilseeds, grain legumes and cereals, particularly in light, draining soils with a high organic content.

The incidence of damage caused by wireworms and false wireworms appears to be increasing with increasing use of minimum tillage and short fallow periods.

7.5.1 False wireworms

In crops, false wireworms are mostly found in paddocks with high contents of stubble and crop litter. They may affect all winter-sown crops. There are many and varied species of false wireworm, but they share some general characteristics. Larvae are cylindrical, hard-bodied, fast-moving, golden brown to black-brown or grey with pointed upturned tails or a pair of prominent spines on the last body segment. Several common groups (genera) of false wireworms are found in south-eastern Australia (Table 13).

Table 13: Management summary of false wireworm

Scientific names	Grey or small false wireworm (*Isopteron* (*Cestrinus*) *punctatissimus*); large or eastern false wireworm (*Pterohelaeus* spp.); southern false wireworm (*Gonocephalum* spp.); bronzed field beetle (*Adelium brevicorne*)
Description	Grey or small false wireworm: Larvae grow to ~9 mm in length, are grey-green, and have two distinct protrusions from the last abdominal (tail) segment (Figure 12), and tend to have a glossy or shiny exterior. They are most easily recognised in the soil on sunny days, when their bodies are reflective. The adults are slender, dark brown and grow to ~8 mm in length. Eggs are <1 mm in diameter. There are several species of this genus, but *I.* punctatissimus appears to be the species most associated with damage Large or eastern false wireworm: The largest group of false wireworms, they are the most conspicuous in the soil and grow up to 50 mm in length. Light cream to tan, with tan or brown rings around each body segment, giving the appearance of bands around each segment (Figure 12). The last abdominal segment has no obvious protrusions, although under a microscope, there are a number of distinct hairs. Adults are large, conspicuous and often almost ovoid beetles with black, shiny bodies (Figure 13) Southern false wireworm: Grows to ~20 mm long and has body colour and marking similar to the large false wireworm. Adults are generally dark brown-grey, oval beetles, and sometimes have a coating of soil on the body. Adults have the edges of the body flanged, hence the common name pie-dish beetles Bronzed field beetle: Larvae are shiny dark brown, grow to 12 mm long, and are cylindrical with two distinct, upturned spines on the end of the body. Adults are shiny black with a slight bronze appearance, grow to 11 mm long and are present from spring to autumn. There is one generation per year
Similar species	Several species of false wireworms may occur in any particular crop, depending on locality, soil type, organic matter and tillage practices
Crops attacked	Newly germinated cereals, cotton, soybeans, sunflowers. The larger false wireworms can cause damage to most field crops
Damage	Larvae feed on germinating seed and chew on seedling roots and shoots, resulting in patchy stands, which can be large enough to require re-sowing. The larvae can hollow out germinating seed, sever the underground parts of young plants, or attack the aboveground hypocotyl or cotyledons Damage is most severe in crops sown into dry seedbeds and if germination is slowed by continued dry weather, then if crop growth is slowed in cold, wet conditions so that crops are slow to grow away from insect damage Adults chew on seedlings at or above ground level, ring-barking or completely cutting the stem[32]

32 DAF Qld (2010) False wireworm. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects/false-wireworm

Monitor	Crops should be sampled immediately before sowing. Two methods are available, although neither is completely reliable is because larvae change their behaviour according to soil conditions, particularly soil moisture and temperature: (*i*) Soil sampling: Take at least five random samples from the paddock. Each sample should consist of the top 20 mm of an area of soil 0.50 m by 0.50 m. Carefully inspect the soil for larvae. Calculate the average density per m^2 (i.e. average number of larvae found in the samples x 4). (*ii*) Seed baits: Pre-soak ~200–300 g of a large seed bait (e.g. any grain legume) for 24 h. Select 5–10 sites in the paddock, place a handful of the soaked seed into a shallow hole (50 mm), and cover with ~10 mm of soil. Mark each hole with a stake, and re-excavate after ~7 days. Inspect the seed and surrounding soil for false wireworm larvae. Most likely to be successful when there is some moisture within the top 100 mm of soil
Control	Control should be considered if the average number from soil sampling is >10 small false wireworms or 10 of the larger false wireworms Chemical control: for larvae, use seed dressings or in-furrow sprays. For adults, use cracked grain baits. See Pest Genie or APVMA for current chemical options. Cultural control: Clean cultivation over summer will starve adults and larvae by exposing them to hot dry conditions, thus preventing population increases. Suitable crop rotations may also limit increases in populations If damage occurs after sowing, no treatment is available, other than resowing bare patches with an insecticide treatment

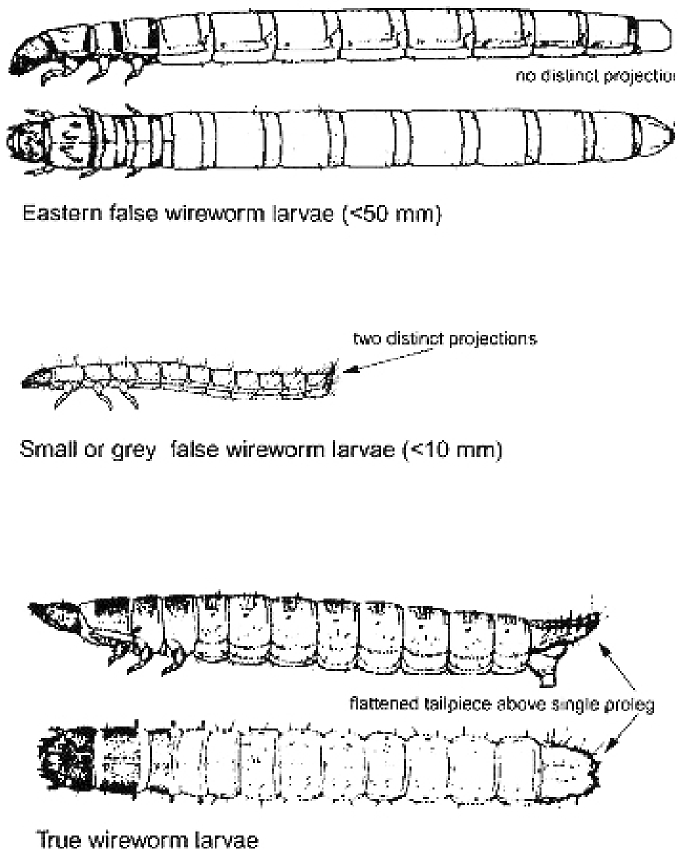

Figure 12: Comparison of larvae: two common species of false wireworm and a 'generalised' true wireworm.

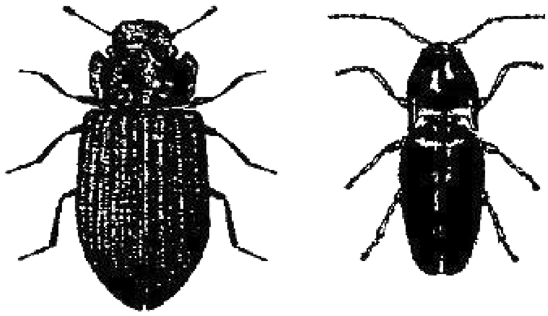

Figure 13: Adult (beetles) of the false wireworm (left) and true wireworm (right). [33]

Larvae of most false wireworm species prefer to feed on decaying stubble and soil organic matter. When the soil is reasonably moist, the larvae are likely to aggregate in the top 10–20 mm where the plant litter is amassed. When the soil dries, the larvae move down through the soil profile, remaining in or close to the subsoil moisture, and occasionally venturing back to the soil surface to feed. Feeding is often at night when the soil surface becomes dampened by dew.

Nothing is known of the conditions that trigger the switch in the feeding of false wireworms from organic matter and litter to plants. Significant damage is, however, likely to be associated with soils that remain dry for extensive periods. Larvae are likely to stop feeding on organic matter when it dries out, and when the crop plants provide the most accessible source of moisture.

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.

Crop residues and weedy summer fallows favour survival of larvae and over-summering adult beetles.

7.5.2 True wireworms

These slow-moving larvae tend to be less common, although always present, in broadacre cropping regions and are generally associated with wetter soils than is the case for false wireworms (Table 14).

Table 14: Management summary of true wireworm

Scientific name	*Agrypnus* spp.
Description	Larvae grow to 15–40 mm, are soft-bodied, flattened and slow moving. This distinguishes them from false wireworms, which are hard bodied, cylindrical and fast moving. Colour ranges from creamy yellow in the most common species to red-brown; head is dark brown and wedge-shaped. The tailpiece is characteristically flattened and it has serrated edges (Figure 12). Adults are known as click beetles for 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 13)
Similar species	Larvae are similar to false wireworm
Crops attacked	All field crops
Damage	Larvae will attack successive seedlings as they emerge. Larvae bore into germinating seed and chew on seedling roots and shoots resulting in reduced vigour or seedling death. [34] The damage is similar to that of false wireworms, except that most damage is below the soil surface
Monitor	As for false wireworm

33 G McDonald (1995) Wireworms and false wireworms. Agriculture Victoria, DEDJTR, http://agriculture.vic.gov.au/agriculture/pest-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms

34 DAF Qld (2010) True wireworm, click beetle or sugar-cane wireworm. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects/true-wireworm

Control	As for false wireworm. Wireworms can be controlled only if they are detected in the seedbed before sowing. Insecticide can be applied to the soil with fertiliser, or seed can be treated

There may be one generation or several per year, depending on species. Most damage occurs from April to August and adults emerge in spring. True wireworms prefer low-lying, poorly drained paddocks and are less common in dry soils. Adults are typically found in summer and autumn in bark, under wood stacks or flying around lights.

Adult beetles emerge in spring and summer, mate and lay eggs, and then may spend a winter sheltering under the bark of trees. The connection between trees and adult beetles may explain why damage is often, but not always, most pronounced on tree lines. True wireworms have a long life in the soil and are active all year, even in winter.

More information

NSW DPI: Insect and mite control in filed crops 2013

DAF Qld: False wireworm

DAF Qld: True wireworm, click beetle or sugar-can wireworm

7.6 Weevils

Weevils are a diverse group of beetles commonly found in Australian grain crops (Table 15, Figure 14). Adult weevils appear very different from the larvae. Adults have a hardened body, six prominent legs and an elongated, downward-curved head forming a 'snout'. Larvae are legless, maggot-like in shape and may be confused with fly larvae. Weevil larvae have a small, hardened head capsule.

Crop weevils feed on vegetative parts of crop plants, including the roots, stems, shoots, buds and leaves. Both adults and larvae can be damaging to plants, depending on the species, crop type and time of year. Typical feeding damage observed is scallop-shaped holes along the edges of leaves.

Weevils can be difficult to control with chemicals because of their secretive habits. Several species are also patchy in their distribution within paddocks. For some species, seed treatments and foliar insecticides can provide a level of control.

Weevils are typically favoured by minimum tillage and stubble retention. Cultivation, burning and reducing the amount of stubble will reduce the suitable habitat for weevils and hence their number. Identification of crop weevils is important when making control decisions. The distinctive appearance of weevils means that they are unlikely to be confused with other beetles. However, distinguishing between the many species of weevil is difficult. Crop weevils: the Back Pocket Guide is designed to assist growers to identify the most commonly observed weevils in cropping regions. [35]

Weevil damage can occur at any time of the season, but feeding during autumn and early winter is typically the most critical. Inspect paddocks and nearby weeds prior to sowing and monitor crops for signs of seedling damage and bare patches within paddocks. Look for signs of chewing damage on plants, often characterised by scallop-shaped holes along the leaf margins, ring-barking of seedlings, and loss of plant vigour. Searches may need to be undertaken during the night because is when weevils are most active.

Weevils, particularly larvae, can be difficult to control with chemicals because of their subterranean habits, meaning that they remain protected from insecticide exposure. Exceptions are the vegetable and grey-banded leaf weevils, whose larvae also feed on foliage. A few registered products are available for the active stages of several weevil species.[36]

[35] GRDC (2013) Crop weevils: the Back Pocket Guide. GRDC, http://www.grdc.com.au/GRDC-BPG-CropWeevils

[36] **cesar** (2015) Weevil pests. PestFacts south-eastern, issue 2, May 2015. **cesar**, http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2015/pestfacts-issue-no-2-22nd-may-2015/weevil-pests/

Table 15: Description of common weevil species

Weevil species	Adult length (mm)	Distinctive features of adult weevils	Larval head capsule colour
Fuller's rose	8	Yellow or grey stripe on thorax and abdomen	Light
Grey-banded leaf	8	Pale band on rear of abdomen	Dark
Mandalotus	3–5	Dull brown, paddle-shaped bristles; short snout	Yellow-brown
Sitona	5	Three white strips on thorax; broad snout	Brown
Small lucerne	7	Less distinct lateral stripes than whitefringed	Light
Spinetail	7	Wing covers taper to spine (females); longer snout	Yellow
Spotted vegetable	5–7	Mottled–specked; longer snout	Brown
Whitefringed	10–15	Light lateral stripes	Light
Vegetable	10	Light-coloured 'V' at rear of abdomen	Brown

Figure 14: Small lucerne weevil (left) and Fuller's rose weevil (right). (Photos: **cesar***)*

7.7 Cockchafers

There are three main types of cockchafer pests (Table 16).

The yellowheaded cockchafer (Figure 15) affects cereal crops across south-eastern Australia, including New South Wales. Yellowheaded cockchafers caused major damage to pastures in the Tablelands of NSW in 2013, 2014 and 2015. [37]

Blackheaded cockchafers are found in high-rainfall areas >480 mm. They feed on foliage and their presence is indicated by green material in their tunnels. Larvae live underground in tunnels and come to the surface to feed at night. They are usually surface in response to rains and heavy dews. [38]

The larvae of redheaded cockchafer are soil dwelling and feed on the roots of plants and other decaying soil material. [39]

Table 16: Management summary of cockchafers

Scientific names	Yellowheaded cockchafer, *Sericesthis* spp.; blackheaded pasture cockchafer, (*Acrossidius tasmaniae*; redheaded pasture cockchafer, *Adoryphorus coulonii*
Description	Yellowheaded cockchafer: Larvae are creamy-grey with a yellow head. When fully grown in winter they are ~25–30 mm long. The grubs live in the soil until mid–late summer, when they emerge as brownish yellow to reddish brown beetles ~10–15 mm long Blackheaded cockchafer: Larvae are soft, whitish C-shaped grubs with three pairs of yellowish legs and a hard, black head capsule. When fully grown in winter they are ~20 mm long. The grubs live in the soil until mid–late summer, when they emerge as shiny black beetles ~10–12 mm long Redheaded pasture cockchafer: Larvae are soft, whitish C-shaped grubs with three pairs of yellowish legs and a hard, reddish brown head capsule. Newly hatched larvae are 5 mm long but when mature reach up to 30 mm. Adults are stout, shiny reddish black beetles ~8 mm wide and up to 15 mm long. The life cycle is two years, with the larval stage completed mostly underground. Adult beetles emerge from the soil from late winter to early spring and fly at dusk to mate before the females lay their eggs into the soil
Crops attacked	Yellowheaded cockchafer: Predominantly a pest in cereals but may also attack pastures Blackheaded cockchafers: Pastures and cereals Redheaded pasture cockchafers: Pastures and some cereal crops
Damage	Yellowheaded cockchafers: Damage plants by feeding directly on the roots or damage roots while they are foraging for decayed organic matter in the area Blackheaded cockchafers: Damage usually occurs to cereals at seedling stage. Can cause large bare patches in crops during late autumn and early winter
Monitor	Yellowheaded cockchafers: Crops sown into long-term pasture paddocks are vulnerable. Monitor susceptible paddocks prior to sowing and throughout winter. Inspect paddocks by digging to a depth of 10–20 cm with a spade and counting the larvae present Blackheaded cockchafers: Monitor pastures and cereal crops from May to late June. Inspect susceptible paddocks prior to sowing by digging to 10–20 cm with a spade and counting the number of larvae present. This should be repeated 10–20 times to get an estimate of larval numbers. Four larvae per spade square is roughly equivalent to 100 larvae/m^2 Redheaded cockchafer: Dig in the affected areas or look on the soil surface for tunnel entrances

37 **cesar** (2015) Yellowhead cockchafers. PestFacts south-eastern. **cesar**, https://www.grdc.com.au/~/media/Documents/EDM/PestFacts5_2015pdf.pdf

38 **cesar** (2015) Blackheaded pasture cockchafer. PestFacts south-eastern. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Blackheaded-pasture-cockchafer

39 **cesar** (2008) Redheaded pasture cockchafer. PestFacts south-eastern June 2008, http://cesaraustralia.com/sustainable-agriculture/identify-an-insect/insect-gallery/pest-insects/beetles-and-weevils/redheaded-pasture-cockchafer/

Control	Yellowheaded cockchafers: Larvae are unlikely to be affected by foliar applications of insecticides. A seed treatment is now for low–moderate populations. Spring-prepared fallows will help to reduce damage in the following year. Intensively grazing in spring, summer and autumn will make eggs and larvae in the topsoil more susceptible to desiccation and predation. Birds, parasitic wasps and flies are the most effective natural enemies. Birds prey on larvae after cultivation. *Metarhizum* spp. are pathogenic fungi that can attack and reduce cockchafer populations [40] Blackheaded cockchafers: Birds, parasitic wasps and flies are the most effective natural enemies. Birds prey on larvae after cultivation. Pathogenic fungi *Metarhizum* spp. and *Cordyceps gunnii* attack pasture cockchafers and can have a devastating influence in local populations. Cultivating before sowing, or sowing with soil disturbance, will expose larvae to predation. Avoid overgrazing pastures during late spring and early summer because these areas will be favoured for egg-laying by adult females. Several foliar insecticides are registered and are effective against larvae that are actively feeding above the surface, and should be applied just prior to rainfall or dews. Once larvae mature, they will stop feeding and stay belowground. Insecticide sprays should be applied before June Redheaded cockchafer: No synthetic insecticides provide effective control because of their subterranean feeding habits. Re-sowing areas made bare by cockchafer damage by using a higher seeding rate is often the most effective strategy

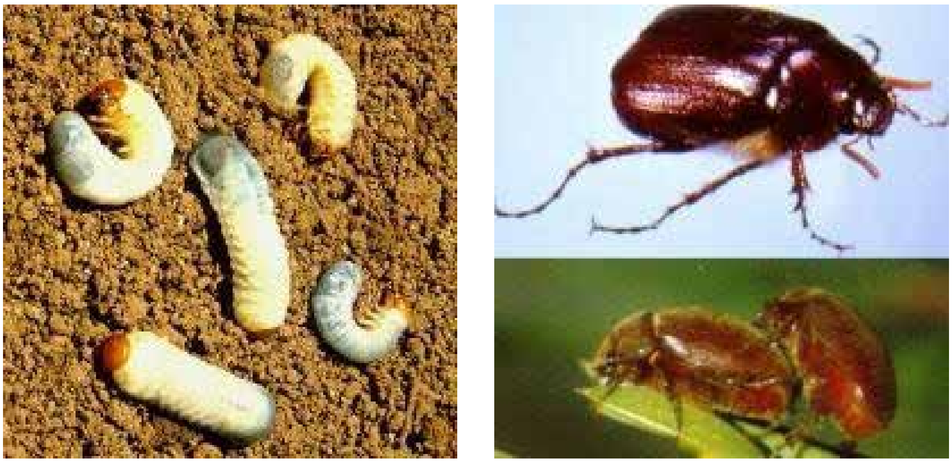

Figure 15: Yellowheaded cockchafer larvae (left panel) and adults (right panels). (Photos: DAFWA)

40 **cesar**. Yellowheaded cockchafer. PestNotes southern. **cesar**, http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Yellowheaded-cockchafer

7.8 Webworm (*Hednota spp.)*

The pasture webworm (Figure 16) is a relatively minor native grass-feeding pest of pastures but can cause large losses to establishing cereals and grass pastures in Victoria, South Australia, New South Wales and Western Australia. There are four species of pasture webworm. [41]

Webworm caterpillars are seldom seen because they move to ground level only when conditions are cool and damp, usually at night. They may be found in their web-lined tunnels from which plant parts may be seen protruding. The caterpillars are pale to deep brown with a tinge of the green gut contents showing through. The head appears black or dark brown. Fully grown caterpillars are ~15 mm long.

Caterpillars hatch from eggs laid among grass in autumn and they feed throughout winter. Spring and summer are passed in the tunnels as resting-stage caterpillars. After this, they proceed through the pupal stage and emerge as adult moths, which are ~10 mm long and may be seen flying in large numbers on autumn nights. By day, they hide in dry grass, the colour of which they closely resemble.

Large areas of emerging cereal crops may be destroyed by the continual chewing damage of a heavy webworm infestation. The caterpillars sever leaves or whole plants, which they scatter on the ground or pull into holes near the plants. In pasture, the grass component may be removed from large areas.

The paddock conditions in autumn and weather are important in determining webworm numbers. Eggs will not be laid in great numbers and they will not survive well in a bare paddock or in stubble. Grassy situations favour survival. Cultivations leading to a weed-free paddock over a 3-week period destroy the young stages, but reduced-tillage cropping methods allow greater survival. Hot and dry conditions during May and June, resulting in a lack of feed, could destroy most webworms. If one-quarter of the plants are damaged at, or just after, emergence, spraying should not be delayed, because continued feeding will kill many plants and result in bare ground or thin areas. [42]

Figure 16: Webworm larvae (left) and moth (right). (Photos: DAFWA)

41 **cesar**. Pasture webworm. PestNotes southern. ceasr, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Pasture-webworm

42 DAFWA (2015) Oats: insect pests. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-insect-pests?page=0%2C1#smartpaging_toc_p1_s1_h3

7.9 Lucerne flea (*Sminthurus viridis*)

Lucerne fleas usually spring from the plants when approached, using a special organ situated underneath the body. The lucerne flea is a dumpy looking, and wingless creature of varied colour, but the larger specimens of 2–4 mm are predominantly green or yellow (Figure 17).

The first soaking autumn rains cause oversummering egg batches to hatch. Several generations may then develop over the growing period, depending up the weather. Eggs are laid in the soil and usually hatch in a few days. With the onset of warm and dry conditions in spring, the resting-stage eggs, which are able to withstand summer conditions, are laid.

Pastures, legume crops and cereals may be seriously retarded by the lucerne flea, and seedling death may occur in heavy infestations. Frequently, green leaf tissues are eaten, leaving a surface of the leaf as a whitish film. Severely affected areas appear from a distance to be bleached.

The lucerne flea is favoured by heavy soils and cannot live in very sandy situations. It is also dependent on plentiful moisture. Control in crops and pastures may be obtained with systemic or contact insecticides, as discussed for RLEM. A predatory mite, the *Bdellodes* mite, is present over most of the area occupied by lucerne flea and exerts a useful level of control. Another predatory mite, the *Neomolgus* mite, was introduced by the CSIRO and has been released many agricultural areas. It will extend the area and level of biological control. [43]

Figure 17: Lucerne flea. (Photo: DAFWA)

[43] DAFWA (2015) Oats: insect pests. Department of Agriculture and Food Western Australia, https://www.agric.wa.gov.au/oats/oats-insect-pests?page=0%2C3

GRDC Grains Research & Development Corporation

7.10 Australian plague locust (*Chortoicetes terminifera)*

Australian plague locust can cause severe damage to pastures and a range of field crops if they are not controlled. They attack crops from flowering to maturity.

Newly emerged nymphs are about the size of houseflies and hop actively. Adults have a characteristic black tip to the hind wing. Swarming locusts are light brown, but solitary individuals may be green or yellow.

Two generations occur annually. Nymphs of the first generation appear when soil temperatures rise in spring. Attainment of adulthood may take 4–8 weeks depending on climatic conditions. Eggs laid by the first generation require at least 21 days to hatch and will hatch only if sufficient soil moisture is present. Eggs laid by the second generation enter a resting phase, which enables them to overwinter.

Adult locusts will eat almost any green plant material, but crops most at risk are ripening cereals in early summer, summer pastures and green pasture growth following summer rain.[44]

More information

Australian Plague Locust Commission

NSW DPI: Locust damage in cops and pastures

The Australian Plague Locust Commission (APLC) undertakes monitoring of locust populations in inland eastern Australia throughout the year. Current locust situations are regularly updated, and the APLC will report whether a major nymph infestation is expected to develop and hatch and in which region. The APLC is jointly funded by the Australian Government and the member states of New South Wales, Victoria, South Australia and Queensland. For further information on the current locust situation, including areas that are most likely to be affected, refer to the APLC and NSW DPI websites. [45]

7.11 Snails

Snail numbers can explode in seasons with wet springs, summers. Snails appear to build up most rapidly in canola, field peas and beans. However, they can feed and multiply in all crops and pastures. Baiting before egg laying is therefore vital. Timing and choice of controls will depend on the season. Baiting should be ceased 8 weeks before harvest to avoid bait contamination in grain.

Understand the factors that determine effectiveness of control. Monitor snails regularly to establish numbers, types, activity and success of controls. To control snails, you will need to apply a combination of treatments throughout the year.

Snails are a mollusc with a rasping tongue and one single muscular 'foot' for movement. Much of their body is encased in a shell, which they secrete as they grow.

Snails consume cotyledons and this may resemble crop failure. Shredded leaves, chewed leaf margins, and irregular holes all occur as a direct result of feeding damage by snails. They generally invade from crop edges.

Free-living nematodes carrying bacteria that cause snail death may help to reduce populations under certain field conditions. Hard grazing of stubbles, cabling and/or rolling of stubbles, stubble burning, cultivation, and removal of summer weeds and volunteers are all effective management options. Molluscicidal baits are effective on mature snails, and IPM-compatible, but can be less effective on juveniles. [46]

44 **cesar** (2009) Plague locusts. PestFacts south-eastern September 2009, **cesar**, http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2009/pestfacts-issue-no-9-4th-september-2009/australian-plague-locusts/

45 **cesar** (2009) Plague locusts. PestFacts south-eastern September 2009, **cesar**, http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2009/pestfacts-issue-no-9-4th-september-2009/australian-plague-locusts/

46 CropPro. Snails. Pests in canola. CropPro, http://www.croppro.com.au/cb_pages/pests_in_canola_-_in_crop.php?category_id=2382

7.12 Slugs

Typically, the grey field slug *(Deroceras reticulatum)* is 35–50 mm long and light grey to fawn, with dark brown mottling (Figure 18). When disturbed, it will exude a sticky, milky secretion over its body. The black-keeled slug (*Milax gagates*) is 40–60 mm long and uniform black or brown with a ridge (keel) down its back (Figure 19). It can burrow to 20 cm underground. [47]

Figure 18: Grey field or reticulated slug. (Photo: M Nash)

Figure 19: Black-keeled slug. (Photo: M Nash)

Slugs are hermaphrodites; therefore, both individuals of a mating pair lay eggs. They will breed whenever moisture and temperature conditions are suitable—generally from mid-autumn to late spring. Eggs are laid in batches in moist soils and they will hatch within 3–6 weeks, depending on temperature. Juveniles look like smaller versions of the adult.

Slugs feed aboveground on stems and leaves, and belowground on seeds, shoots and roots. Damage is greatest when seedling growth is slow from cool, wet or dry conditions. Grey field slugs are mainly surface-active, whereas black-keeled slugs burrow and can feed directly on germinating seeds. Slugs can be underestimated as

[47] GRDC (2013) Slug identification and management. GRDC Slug control Fact Sheet, March 2013, http://www.grdc.com.au/~/media/412EEE56898A4AFB8B50409EC87FEBFE.pdf

pests because they are nocturnal and shelter during dry conditions, and therefore are not generally visible during daylight hours. [48]

Slugs damage newly sown crops and pasture, and damage is often difficult to detect or is incorrectly attributed to agronomic factors. If the population is large, damage to seedlings can be extensive. The black-keeled slug is more problematic in drier environments such as South Australia, although it is widespread throughout south-eastern Australia. [49,50]

Cultivation prior to sowing, delaying sowing after summer cover has been sprayed out, stubble and weed removal, and baiting are all effective methods for reducing slug populations. When slug pressure is high, baiting alone may not provide total crop protection. [51]

7.13 Insect-monitoring techniques for field crops

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 knowledge of, and the ability to identify, the insects present, but also good sampling and recording techniques and a healthy dose of common sense.

7.13.1 Factors that contribute to quality monitoring

Knowledge of likely pests/beneficials and their life cycles is essential when planning a monitoring program. As well as visual identification, you need to know where on the plant to look and the best time of day to get a representative sample.

Monitoring frequency and pest focus should be directed at crop stages likely to incur economic damage. Critical stages may include seedling emergence and flowering/grain formation.

Sampling technique is important to ensure that a representative portion of the crop has been monitored, because pest activity is often patchy. Defining sampling parameters (e.g. number of samples per paddock and number of leaves per sample) enables sampling consistency. Actual sampling technique, including sample size and number, will depend on crop type, age and paddock size, and is often a compromise between the ideal number and location of samples, and what is practical considering time constraints and distance covered.

Random sampling should be balanced with areas of obvious damage. Random sampling aims to give an overall picture of what is happening in the field, but any obvious hot-spots should also be investigated. The relative proportion of hotspots in a field must be kept in perspective with less heavily infested areas.

7.13.2 Keeping good records

Accurate recording of results of sampling is critical for good decision making and for being able to review the success of control measures. Monitoring record sheets should show the following:

- numbers and types of insects found (including details of adults and immature stages)

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48 GRDC (2013) Slug identification and management. GRDC Slug control Fact Sheet, March 2013, http://www.grdc.com.au/~/media/412EEE56898A4AFB8B50409EC87FEEBE.pdf

49 G Baker (2009) Pests of canola and their management. Ch. 9. In Canola best practice management guide for south-eastern Australia. (Eds D McCaffrey, T Potter, S Marcroft, F Pritchard) GRDC, https://www.grdc.com.au/uploads/documents/GRDC_Canola_Guide_All_1308091.pdf

50 GRDC (2013) Slug identification and management. GRDC Slug control Fact Sheet, March 2013, http://www.grdc.com.au/~/media/412EEE56898A4AFB8B50409EC87FEEBE.pdf

51 CropPro. Slugs. Pests in canola. CropPro, http://www.croppro.com.au/cb_pages/pests_in_canola_-_in_crop.php?category_id=2381

- size of insects (particularly important for larvae)
- date and time
- crop stage and any other relevant information (e.g. row spacings, weather conditions, and general crop observations)

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 whether a treatment has been effective. If you have trouble identifying damage or insects present, keep samples for later reference.

Records of spray operations should include:

- date and time of day
- conditions (wind speed, wind direction, temperature, presence of dew and humidity)
- product(s) used (including any additives)
- amount of product(s) and volume applied per hectare
- method of application including nozzle types and spray pressure
- any other relevant details

7.13.3 Sampling methods

Beat sheet

A beat sheet is the main tool used to sample row crops for pests and beneficial insects. Beat sheets are particularly effective for sampling caterpillars, bugs, aphids and mites. A standard beat sheet is made from yellow or white tarpaulin material with heavy dowel on each end. Beat sheets are generally 1.3–1.5 m wide and 1.5–2.0 m deep (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 from being flung through or escaping through this row.

To use the beat sheet, place one edge at the base of plants in the row to be sampled. Drape the other end of the beat sheet over the adjacent row. This may be difficult in crops with wide row spacing (≥1 m); in this case, spread the sheet across the inter-row space and up against the base of the next row.

Using a 1-m-long stick, shake the plants in the sample row vigorously in the direction of the beat sheet ~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 datasheets to record type, number and size of insects found on the beat sheet. One beat does not equal one sample. The standard sample unit is five, non-consecutive 1-m-long sections of row, taken within a 20-m radius, i.e. five beats = one sample unit. This should be repeated at six locations in the field (i.e. 30 beats per field).

Increasing the number of samples taken increases the accuracy of the assessment of pest activity, particularly for pests that are patchily distributed, such as pod-sucking bug nymphs.

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 they are more easily seen at this time. Some pod-sucking 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 when they are sampled, so it is important to count them first.

In very windy weather, bean bugs, mirids and other small insects are likely to be blown off the beat sheet. Using the beat sheet to determine insect numbers is difficult when the field and plants are wet.

Although the recommended method for sampling most insects is the beat sheet, visual checking in buds and terminal structures may also be needed to supplement beat-sheet counts of larvae and minor pests. Visual sampling will also assist in finding eggs of pests and beneficial insects.

Most thresholds are expressed as pests per m^2. Hence, insect counts in crops with row spacing <1 m must be converted to number of pests/m^2. To do this, divide the 'average insect count per row metre' across all sites by the row spacing (in metres). For example, in a crop with a row spacing of 0.75 m (75 cm), divide the average pest counts by 0.75.

Other sampling methods

Visual checking is not recommended as the sole form of insect checking. Leaflets or flowers should be separated when looking for eggs or small larvae, and leaves checked for the presence of aphids and silverleaf whitefly. If required, dig below the soil surface to assess soil insect activity.

Visual checking of plants in a crop is also important for estimating how the crop is progressing in terms of average growth stage, 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. It is also useful if the field is wet. Sweep-netting works best for smaller pests found in the tops of smaller crops, is less efficient against larger pests such as pod-sucking bugs, and it is not practical in tall crops with a dense canopy. At least 20 sweeps must be taken along a single 20-m row.

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. [52]

7.14 PestFacts

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.

More information

cesar: Insect gallery

cesar PestFacts: Grass anthelids

GRDC Update Papers: Don't forget the good guys—recognising and identifying beneficial insects in your paddock

GRDC Ute Guides: Insects

GRDC Update Papers: Insect pests—resistance, virus vectors and lessons from 2014

NIPI: Insect identification aids

[52] DAF Qld (2012) Insect monitoring techniques for field crops. Department of Agriculture and Fisheries Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/insect-monitoring

SECTION 8

Nematode management

Root-lesion nematodes (RLN; *Pratylenchus* spp.) are microscopic, worm-like animals that extract nutrients from plants, causing yield loss. To the north of the region, the predominant RLN, is *P. thornei* while in the southern parts the *P. neglectus* is the more dominant species. RLN are found in three-quarters of fields tested in central NSW, northern NSW and Queensland. [1]

Oats in the northern region is considered resistant to *P. thornei* and has intermediate susceptibility to *P. neglectus.* [2]

Intolerant crops such as wheat and chickpeas can lose 20–60%[3] in yield when nematode populations are high. Resistance and susceptibility of crops can differ for each RLN species; for example, sorghum is resistant to *P. thornei* but susceptible to *P. neglectus*. A tolerant crop yields well when large populations of RLN are present (the opposite is intolerance). A resistant crop does not allow RLN to reproduce and increase in number for the following crop (the opposite is susceptibility).[4]

Successful management relies on:

- farm hygiene to keep fields free of RLN
- growing tolerant varieties when RLN are present, to maximise yields
- rotating with resistant crops to keep RLN at low levels[5]

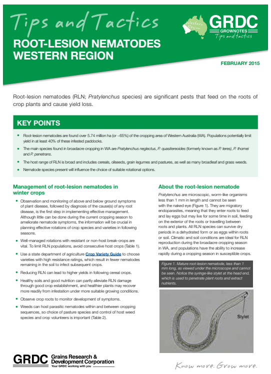
Nematodes reduce yields in intolerant crops by reducing the amount of water and nutrients available for plant growth by compromising plant roots.

Nematodes also impose early stress that reduces yield potential despite the availability of water and nutrients. [6]

Other nematodes that can potentially cause problems in the northern region include Cereal cyst nematode (CCN) (*Heterodera avenae*), the stunt nematode (*Merlinius brevidens*) and stem nematode (*Ditylenchus dipsaci*). [7 8]

Management of RLN in winter crops includes:

More information



[Root-Lesion Nematodes, GRDC Tips and Tactics](#)

1 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

2 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

3 KJ Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes: crop rotations to manage nematodes – key decision points for the latter half of the year, Bellata. GRDC Grains Research Update, July 2013.

4 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

5 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

6 GRDC (2014), How nematodes reduce yield. http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/How-nematodes-reduce-yield

7 GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

8 GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

- Observation and monitoring of above- and below-ground symptoms of plant disease followed by diagnosis of the cause(s) of any root disease are the first steps in implementing effective management. Although little can be done during the current cropping season to ameliorate nematode symptoms, the information will be crucial in planning effective rotations of crop species and varieties in following seasons.
- Well-managed rotations with resistant or non-host break-crops are vital. To limit RLN populations, avoid consecutive host crops (Table 1).
- Use a state department of agriculture Crop Variety Guide to choose varieties with high resistance ratings. These will result in fewer nematodes remaining in the soil to infect subsequent crops.
- Reducing RLN can lead to higher yields in following cereal crops.
- Healthy soils and good nutrition can partly alleviate RLN damage through good crop establishment, and healthier plants may recover more readily from infestation under more suitable growing conditions.
- Observe crop roots to monitor development of symptoms.
- Weeds can host parasitic nematodes within and between cropping sequences, so choice of pasture species and control of host weed species and crop volunteers is important (Table 2). [9]

Table 1: Resistance of major crop broadacre species to Pratylenchus neglectus, P. quasitereoides and P. penetrans

Susceptible	Moderately susceptible	Resistant
P. neglectus		
Wheat	Canola	Field peas
Barley	Oats	Lupins
Chickpeas	Durum wheat	Faba beans
		Lentils
		Triticale
		Rye
		Safflower
		Narbon beans
***P. quasitereoides* (formerly *P. teres*)**		
Wheat	Canola	Field peas
Barley		Lupins
Oats		
P. penetrans		
Field peas	Barley	
Lupins	Canola	
Chickpeas		
Oats		
Durum wheat		
Wheat		
Triticale		
Faba beans		
Wild oats		
Wild radish		

Information for *P. quasitereoides* and *P. penetrans* is based on samples received by Agwest Plant Laboratories for diagnosis, combined with data from preliminary field and glasshouse trials.

9 GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

Table 2: Resistance of pasture species to Pratylenchus neglectus

Cultivar	Species	Resistance rating
Tanjil lupin	*Lupinus angustifolius*	R
Charano yellow serradella	*Ornithopus compressus*	R
Flamenco sulla	*Hedysarum coronarium*	R
Yelbini yellow serradella	*Ornithopus compressus*	R
Margurita French serradella	*Ornithopus sativus*	R
Cadiz French serradella	*Ornithopus sativus*	MR
Santorini yellow serradella	*Ornithopus compressus*	MR
Erica French serradella	*Ornithopus sativus*	MR
Hykon rose clover	*Trifolium hirtum*	MS
Electra purple clover	*Trifolium purpureum*	MS
Sceptre lucerne	*Medicago sativa*	MS
Mauro biserrula	*Biserrula pelecinus*	S
Casbah biserrula	*Biserrula pelecinus*	S
Caprera crimson clover	*Trifolium incarnatum*	S
Cefalu arrowleaf clover	*Trifolium vesiculosum*	S
Sothis eastern star clover	*Trifolium dasyurum*	S
CFD27 bladder clover	*Trifolium spumosum*	S
2002ESP4 biserrula	*Biserrula pelecinus*	S
Coolamon subterranean clover	*Trifolium subterraneum*	S
Machete wheat	*Triticum aestivum*	S
Nitro Plus Persian clover	*Trifolium resupinatum*	S
Frontier balansa clover	*Trifolium michelianum*	S
Dalkeith subterranean clover	*Trifolium subterraneum*	S
Caliph barrel medic	*Medicago truncatula*	S
Urana subterranean clover	*Trifolium subterraneum*	S
Santiago burr medic	*Medicago polymorpha*	VS
Prima gland clover	*Trifolium glanduliferum*	VS

R - Resistant, MR - moderately resistant, MS - moderately susceptible, S - susceptible, VS - very susceptible

8.1 Background

Root-lesion nematodes use a syringe-like ‘stylet’ to extract nutrients from the roots of plants (Figure 1). Plant roots are damaged as RLN feed and reproduce inside the plant roots. *Pratylenchus thornei* and *P. neglectus* are the most common RLN species in Australia. These nematodes can be found deep in the soil profile (to 90 cm depth) and in a broad range of soil types, from heavy clays to sandy soils. [10] Oats are considered resistant to *P. thornei* and have intermediate susceptibility to *P. neglectus.*

New CSIRO research funded by the GRDC is examining how nematodes inflict damage by penetrating the outer layer of wheat roots and restricting their ability to transport water.

10 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

Figure 1: Microscope image of a root-lesion nematode. Notice the syringe-like 'stylet' at the head end, which is used for extracting nutrients from the plant root. This nematode is less than 1 mm long. (Photo: Sean Kelly, DAFWA)

8.2 Symptoms and detection

Root-lesion nematodes are microscopic organisms that occur in soil and plants. The most reliable way to confirm the presence of RLN is to have soil tested in a laboratory. Fee-for-service testing of soil offered by the PreDicta B root disease testing service of the South Australian Research and Development Institute (SARDI) can determine levels of *P. thornei*, *P. neglectus,* CCN and stem nematodes present. [11]

Similar results can be obtained by soil testing either by manual counting (under microscopes) or by DNA analysis (PreDicta B), with commercial sampling generally at depths of 0–10 cm. [12]

Signs of nematode infection in roots include dark lesions or poor root structure (Figure 2). The damaged roots are inefficient at taking up water and nutrients—particularly nitrogen (N), phosphorus (P) and zinc (Zn)—causing symptoms of nutrient deficiency and wilting in the plant shoots.[13]

[11] KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

[12] R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

[13] KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

Figure 2: Oat plants with roots damaged by RLN. Note lack of root hairs and darkened areas. The shoots show phosphate deficiency, a result of damaged roots having poor uptake of nutrients. (Photo: Doug Sawkins)

8.2.1 What is seen in the paddock?

Above-ground symptoms are often indistinct and difficult to identify. The first signs are poor establishment, stunting, poor tillering of cereals, and plants possibly wilting despite moist soil. Nematodes are usually distributed unevenly across a paddock, resulting in irregular crop growth (Figure 3). Sometimes symptoms are confused with nutrient deficiency and they can be exacerbated by a lack of nutrients.

Figure 3: Above-ground symptoms of RLN, primarily in the form of moisture stress and nutrient deficiency. (Photo: Doug Sawkins)

When roots are damaged by RLN, the plants become less efficient at taking up water and nutrients, and less able to tolerate stresses such as drought or nutrient deficiencies. Depending on the extent of damage and the growing conditions, affected plants may partly recover if the rate of new root growth exceeds the rate at which nematodes damage the roots.

To gain the full picture requires examining what is going on under the ground. Primary and secondary roots of cereals will show a general browning and discoloration and there will be fewer, shorter laterals branching from the main roots.

The root cortex (or outer root layer) is damaged and it may disintegrate.

Diagnosis is difficult and can be confirmed only with laboratory testing. This is essential if identification is sought to species level as all RLN species cause identical symptoms. The PreDicta BTM soil test (SARDI Diagnostic Services) is a useful tool for several nematode species and is available through accredited agronomists. [14]

8.3 Management

There are four key strategies for the management of nematodes (Figure 4):

1. Test soil for nematodes in a laboratory.
2. Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.
3. Choose tolerant varieties to maximise yields (www.nvtonline.com.au). Tolerant varieties grow and yield well when nematodes are present.
4. Rotate with resistant crops to prevent increases in RLN (Table 1, Figure 4). When large populations of RLN are detected, you may need to grow at least two resistant crops consecutively to decrease populations. In addition, ensure that fertiliser is applied at the recommended rate so that the yield potential of tolerant varieties is achieved.[15]

[14] GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

[15] KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

Other considerations include:

1. **Nematicides.** There are no registered nematicides for RLN in broadacre cropping in Australia. Screening of potential candidates is 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 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 (i.e. ability of the variety to yield under RLN pressure) and resistance (i.e. impact of the variety on RLN build-up). Note that varieties and crops often have varied tolerance and resistance levels to *P. thornei* and *P. neglectus*.
4. **Fallow.** Populations of RLN will decrease during a 'clean' fallow, but the process is slow and expensive in lost 'potential' income. Additionally, long fallows may decrease arbuscular mycorrhiza (AM) levels and create more cropping problems than they solve.[16]

The most important management tool is using rotations that effectively reduce RLN populations. In heavily infested paddocks, resistant break-crops should be grown for 1 or 2 years to decrease the population. Resistant varieties should be selected for the following years using a current Crop Variety Guide.

Table 3: Susceptibility and resistance of various crops to root-lesion nematodes [17]

RLN species	Susceptible	Intermediate	Resistant
P. thornei	Wheat, chickpea, faba bean, barley, mungbean, navy bean, soybean, cowpea	Canola, mustard, triticale, durum wheat, maize, sunflower	Canary seed, lablab, linseed, oats, sorghum, millet, cotton, pigeon pea
P. neglectus	Wheat, canola, chickpea, mustard, sorghum (grain), sorghum (forage)	Barley, oat, canary seed, durum wheat, maize, navy bean	Linseed, field pea, faba bean, triticale, mungbean, soybean

Adequate nutrition (especially N, P and Zn) helps crops to compensate for the loss of root function caused by RLN, although this does not necessarily lead to lower nematode reproduction. In field trials in areas infested with *P. neglectus*, yield losses for intolerant wheat ranged from 12% to 33% when minimal levels of P were applied, but losses were reduced to only 5% with a high rate of P (50 kg/ha).

Weeds can play an important role in the increase or persistence of nematodes in cropping soils. Thus, poor control of susceptible weeds compromises the use of crop rotations for RLN management.

Wild oats, barley grass, brome grass and wild radish are susceptible to *P. neglectus*.

Several pasture species and varieties are suitable in rotations to reduce RLN when targeted to the species in your paddock (Table 1), but weeds must be managed because they can strongly influence nematode populations at the end of the pasture phase.

Manage volunteer susceptible crop plants, because they can harbour nematodes.

Nematodes cannot move great distances unaided. However, they can be spread through surface water, and in soil adhering to vehicles and farm machinery. In

16 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

17 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

uninfested areas, good hygiene should be practised. They can also be spread in dust when they are dehydrated over summer.[18]

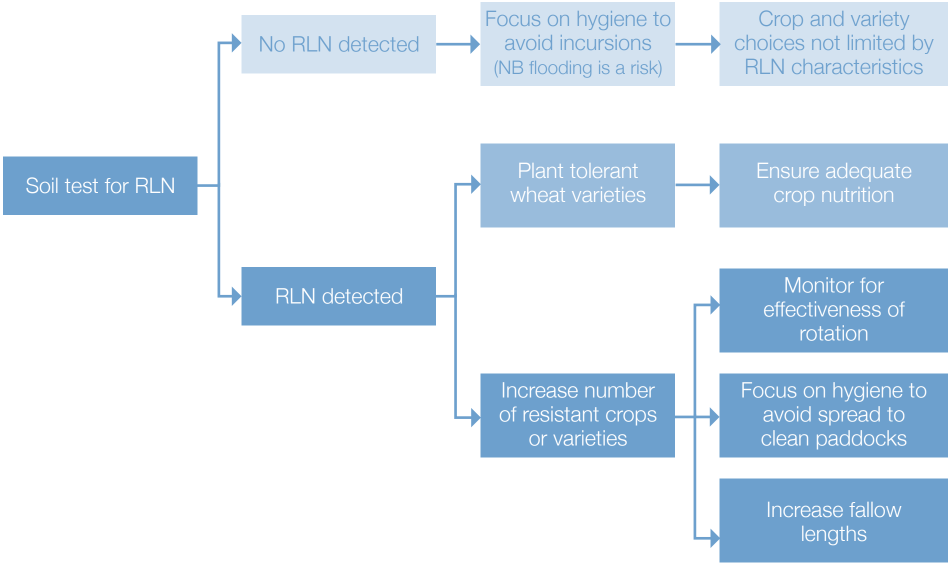


Figure 4: Root-lesion nematode management flowchart.

8.3.1 Crop Rotation

P. neglectus was found in 32% of paddocks (often in combination with *P. thornei*) in the northern region in a survey of 800 paddocks (Thompson *et al.* 2010).

Summer crops that are partially resistant or poor hosts of *P. neglectus* include sunflower, mungbean, soybean and cowpea. When these crops are grown, populations of *P. neglectus* do not increase because the crops do not allow the nematode to reproduce. For winter crops, field peas or faba beans offer resistance to this nematode.

In a field experiment, populations of *P. neglectus* increased after growing grain sorghum. Populations increased from 3.1 times after MR32 (4,400 *P. neglectus*/kg soil) to 7.3 times after MRGoldrush (10,400 *P. neglectus*/kg soil) compared to soil at planting (1,400 *P. neglectus*/kg soil).[19]

Summer crops have an important role in management of RLN. Research shows that when *P. thornei* is present in high numbers, two or more resistant crops in sequence are needed to reduce populations to low enough levels to avoid yield loss in the following intolerant or susceptible crops.[20]

Canola appears to be a good crop for reducing *P. thornei* populations due to its biofumigant potential, but the dependence of subsequent crops on AM fungi should be considered, particularly in the north of the northern grains region.[21]

18 GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

19 GRDC (2013) Summer crop decisions and root lesion nematodes. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes

20 K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes: crop rotations to manage nematodes – key decision points for the latter half of the year, Bellata. GRDC Grains Research Update, July 2013.

21 KJ Owen, TG Clewett, JP Thompson (2010) Pre-cropping with canola decreased Pratylenchus thornei populations, arbuscular mycorrhizal fungi, and yield of wheat. Crop & Pasture Science 61, 399–410.

8.3.2 Sowing time

Yield losses can be exacerbated by delayed sowing and drier conditions, as the plant roots are damaged, impeding the plants ability to uptake water and nutrients.[22]

Delayed sowing into late autumn/winter is likely to see crops initially develop under cooler soil temperatures, thus reducing the rate of root development, especially in the cooler southern parts of the region. Conversely, earlier sown crops establish under warmer soil conditions and have more rapid, early root growth if adequate moisture is available. [23]

In theory, any restriction to root development is likely to inhibit a crop's ability to compensate for nematodes feeding upon these root systems. [24]

New South Wales Department of Primary Industries (NSW DPI) winter cereal time-of-sowing trials at Coonamble, Mungindi, Trangie, Come-by-Chance and Gurley, NSW, in 2011 showed the following:

- Winter crop type and variety choice have a large effect on the build-up of nematode populations in the soil due to differences in their resistance to *P. thornei*.
- This was most pronounced in bread wheat where the variety choice:
  - increased the *P. thornei* population by 1.8–3.6 times (9737 up to 19,719 *P. thornei*/kg soil) at Coonamble, and
  - decreased the *P. thornei* population by 64% between the most susceptible and most resistant varieties at Mungindi (25,448 *v.* 9050 *P. thornei*/kg soil).[25]

Visit www.nvtonline.com.au

More information

http://www.nvtonline.com.au/wp-content/uploads/2013/03/Disease-Rating-Definitions-Nematode-Resistance.pdf

http://www.nvtonline.com.au/wp-content/uploads/2013/03/Disease-Rating-Definitions-Nematode-Tolerance.pdf

8.4 Varietal resistance or tolerance

A tolerant crop yields well when large populations of RLN are present (in contrast to an intolerant crop). A resistant crop does not allow RLN to reproduce and increase in number (in contrast to a susceptible crop).

Tolerance and resistance of oat varieties to nematodes are published each year at www.nvtonline.com.au.

8.4.1 Tolerance

Tolerant varieties are able to perform well in the presence of nematodes, but they may not reduce nematode densities.

Choosing tolerant varieties will limit the yield and economic impact from *P. thornei*; however, some of these varieties still allow high levels of nematode build-up. [26]

8.4.2 Resistance

Resistant varieties will result in fewer nematodes remaining in the soil to infect subsequent crop.

Resistance is the impact of the variety on RLN multiplication. Eradication of RLN from an individual paddock is highly unlikely, so effective long-term management is based on choosing options that limit RLN multiplication. This involves using crop or varieties that have useful levels of *P. thornei* resistance and avoiding varieties that will cause large 'blow-outs' in *P. thornei* numbers.

22 S Simpfendorfer, M Gardner, G McMullen (2012) Impact of sowing time and varietal tolerance on yield loss to the root-lesion nematode *Pratylenchus thornei*. GRDC Grains Research Update, Goondiwindi, March 2012.

23 NSW DPI (2013) Northern Grains Region trial results autumn 2013. NSW Department of Primary Industries

24 NSW DPI (2013) Northern Grains Region trial results autumn 2013. NSW Department of Primary Industries.

25 NSW DPI (2013) Northern Grains Region trial results autumn 2013. NSW Department of Primary Industries.

26 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

Resistance differences between crops

The primary method of managing RLN populations is to focus on increasing the number of resistant crops in the rotation. Knowledge of the species of RLN present is critical, as crops that are resistant to *P. thornei* may be susceptible to *P. neglectus*.

Key crops that are generally considered resistant or moderately resistant to *P. thornei* are sorghum, sunflower, maize, canola, canary seed, cotton, field peas and linseed.

Wheat, chickpeas, faba beans, mungbeans and soybeans are generally susceptible to *P. thornei*, although the level of susceptibility may vary between varieties.

8.5 Other nematodes

A number of other nematodes can affect the farming system.

Pratylenchus penetrans and *P. crenatus* have been reported, but at a very low frequency; *P. quasitereoides* (formerly known as *P. teres*) has been identified only in crops in Western Australia and is not known to occur in other regions of Australia. Other species of RLN may occur, and if this is suspected, you should follow up with your state department of agriculture.

Cereal cyst nematode (CCN; *Heterodera avenae*) is a damaging pathogen of broadacre cereal crops in South Australia and Victoria. It affects wheat, barley, oats and triticale, and can cause yield losses of up to 80%. The damage caused by the feeding nematode results in a proliferation of roots at the feeding site, which forms a knot in the root, giving the plant the characteristic symptoms. CCN has been successfully managed by growing resistant cereal varieties. [27]

There have been isolated reports of cereal cyst nematode (CCN; *Heterodera avenae*) near Tamworth and Dubbo on lighter textured soils and friable black soils. If growers suspect CCN, they should contact a local agronomist. [28]

Stem nematode (*Ditylenchus dipsaci*): Two races of stem nematode have been recorded in South Australia: the oat and the lucerne race. The oat race is found in parts of Yorke Peninsula and the Mid North of South Australia. The main hosts are susceptible oat and faba bean varieties. Symptoms on oats include stunted plants and the bases of each tiller becoming swollen. Other crops such as field peas, chickpeas, canola and lentils are damaged extensively by stem nematode when they are seedlings (i.e. there is seedling intolerance). Symptoms include stunted and distorted leaves and stems. As crops mature, they become both resistant and tolerant. [29]

The stunt nematode (*Merlinius brevidens*) is found widely on northern grain region grain farms. In a survey of ~800 farms, it was found in 73% of paddocks. This nematode prefers similar soil conditions to *P. thornei* (alkaline soils with high clay content) and in 60% of paddocks it was found in soils that also contained *P. thornei* and/or *P. neglectus*. The stunt nematode grazes on the surface of plant roots which causes restricted damage to the surface cells, consequently it is regarded as less destructive than root lesion nematode that cause extensive damage as they feed and migrate within the plant roots. Occasionally, very large populations of the stunt nematode are found in Northern Grain Region farms and although wheat yield loss has not been associated with this nematode, there is a suggestion that symptoms of infection by *P. thornei* were greater when the stunt nematode was also present.

In lighter textured soils, the stubby-root nematode (*Paratrichodorus* sp.) and root-knot nematode (*Meloidogyne* sp.) have been found on cereals and grain legumes. Other RLN occurring away from traditional wheat areas are *Pratylenchus zeae* on maize and

27 GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

28 GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

29 GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

sugarcane and *Pratylenchus brachyurus* on peanuts. There have been isolated reports of cereal cyst nematode (CCN; *Heterodera avenae*) near Tamworth and Dubbo on lighter textured soils and friable black soils. If growers suspect CCN, they should contact a local agronomist.

The reniform nematode (*Rotylenchulus reniformis*) has recently been detected in damaging populations on cotton in the Dawson and Callide Valleys in Central Queensland. [30]

30 GRDC (2015) Tips and Tactics Root-Lesion Nematodes Northern Region, http://www.grdc.com.au/TT-RootLesionNematodes

SECTION 9

Diseases

Diseases can severely affect yield and quality in oats. In some cases, diseases are controlled through simple cultural practices and good farm hygiene. One of the major practices used in the control of diseases is crop rotation.

To minimise the effect of diseases:

- Use resistant or partially resistant varieties.
- Use disease-free seed.
- Use fungicidal seed treatments to kill fungi carried on the seed coat or in the seed.
- Have a planned, in-crop fungicide regime.
- Conduct in-crop disease audits to determine the severity of the disease. This can be used as a tool to determine what crop is grown in what paddock the following year.
- Conduct in-fallow disease audits to determine the severity of the disease (e.g. yellow leaf spot and crown rot). This can also be used as a tool to determine what crop is grown in what paddock the following year.
- Send plant or stubble samples away for analysis to determine the pathogen or strain you are dealing with or the severity of the disease.
- Control summer weeds and volunteer plants that may act as a green bridge.
- Rotate crops. [1]

FAQ

Oats can be infected by diseases, including *barley yellow dwarf virus* (BYDV), that are transmitted by aphids. Early sown crops are more at risk. Sow tolerant varieties or be prepared to control aphids to prevent disease transmission.

Seed dressings will offer some anti-feeding protection for your oat crop against aphids. Imidacloprid is registered for use on cereal crops as a seed dressing for the management of aphids and BYDV spread in cereal crops. For more information, go to the Australian Pesticides and Veterinary Medicines Authority website at www.apvma.gov.au.

[1] DAF Qld (2012) Wheat—diseases, physiological disorders and frost. Department of Agriculture and Fisheries, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

Table 1: Cereal insecticide seed dressings for aphid and barley yellow dwarf virus (BYDV) control 2015 [2]

Active ingredient of insecticide and fungicide Various trade names sometimes available under these active ingredients, concentrations and formulations. See specific labels for details.	**Examples of seed treatment trade name and manufacturer**	**Rate to apply to each 100 kg###**	**Approx. cost to treat 100 kg of seed ($)##**	**Aphid feeding damage suppression (wheat aphid and corn aphid)**	**Reduces spread of BYDV**	**Grazing withholding period (weeks)**
Imidacloprid 180 g/L + tebuconazole 6.25 g/L	Hombre® – Bayer CropScience	400 mL	8.36	✓	✓	9
Imidacloprid 360 g/L + tebuconazole 12.5 g/L	Hombre® Ultra– Bayer CropScience	200 mL	8.03	✓	✓	9
Imidacloprid 180 g/L + triadimenol 56 g/L	Zorro® – Bayer CropScience	400 mL	8.62	✓	✓	9
Imidacloprid 180 g/L + flutriafol 6.25 g/L	Veteran® Plus – Crop Care	400 mL	8.42	✓	✓	9
Imidacloprid 180 g/L + flutriafol 25 g/L	Arrow® Plus – Crop Care (registered for barley only)	400 mL	8.69	✓	✓	9
Imidacloprid – 350 g/L	Gaucho® 350 – Bayer CropScience	200 mL – 400 mL	8.11–16.22	✓	✓	9
Imidacloprid – 600 g/L	Gaucho® 600 – Bayer CropScience Senator® 600 Red – Crop Care	120 mL – 240 mL	6.11–12.21	✓	✓	9

The major diseases of oats in the northern region are the rust suite. Significant production losses can result from either stem rust or leaf rust. With the development of new pathotypes in some regions for stem rust, there are no remaining genetic resistances available in commercially grown varieties to fully protect crops from stem rust.

Leaf rust resistance levels in some varieties provide useful field tolerance to the disease. Monitor crops in season for the presence of these rusts. Rusts can be managed by selecting appropriate varieties for sowing, avoiding sowing later maturing varieties and applying late irrigations, and adjusting grazing management, or can be controlled by the use of foliar fungicides in-crop. [3]

2 NSW DPI (2015) Winter crop variety sowing guide, Department of Primary Industries, New South Wales, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

3 NSW DPI (2015) Winter crop variety sowing guide, Department of Primary Industries, New South Wales, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

Table 2: Guide to oat diseases [4]

Disease/Cause	Symptoms	Occurrence	Spread	Control
Foliar Diseases				
Bacterial stripe blight *Pseudomonas striafaciens* pv. *striafaciens*	Water soaked stripes on leaves, drying to tan/red stripes, leaf death.	More severe in early maturing crops in wetter seasons.	Rain splash, insects, seed-borne.	Nil
Barley yellow dwarf *Barley yellow dwarf virus (BYDV)*	Yellowing, dwarfing of infected plants, floret blasting, leaf reddening in some varieties.	Most common near perennial grass pastures and in early sown crops.	Transmitted by aphids from infected grasses and cereals.	Resistant and tolerant varieties; controlling aphids, insecticidal seed treatments.
Leaf (Crown) rust *Puccinia coronata* f.sp. *avenae*	Orange powdery pustules on upper leaf surface.	In wet seasons; more important on the coast.	Air-borne spores from living plants.	Graze infected crops in autumn, Varieties with the best possible field resistance. Foliar fungicides.
Leaf spots Several fungi	Leaf spots, leaf death.	Usually minor.	Depends on disease.	None.
Red leather leaf *Spermospora avenae*	Long lesions with reddish borders and light centres. Leaves may look and feel leathery.	Higher rainfall, cool wet weather.	Oat stubble. Stubble and rain splash.	Avoid susceptible oat varieties and rotate crops.
Stem rust *Puccinia graminis* f.sp. *avenae*	Reddish-brown, powdery, oblong pustules with tattered edges on leaf and stem; progressive death of plant.	More important inland, from spring to summer in warm, wet weather.	Air-borne spores from living plants.	Early maturing varieties to avoid rust. Foliar fungicides.
Smuts				
Smuts *Ustilago avenae*, *U. segetum* var. *hordei*	Replacement of florets by black sooty mass.	Statewide.	Spores on or in the seed infect the seedling after sowing.	Thorough treatment of seed with appropriate fungicide.

If hay production is the end use for your crop, care must be taken to ensure a quality product is produced, in particular if the hay is headed to the lucrative export market. The table below explores which diseases are of the greatest threat to hay quality.

Table 3: Priority of disease constraints to oaten hay production in Australia [5]

Highest priority	High priority	Medium priority
Septoria blotch	Barley yellow dwarf (BYDV)	Root lesion nematodes
Leaf rust	Windburn	Aphids
Stem rust	Bacterial blight diseases	Red leather leaf
Cereal cyst nematode (CCN)	Stem nematode	
Annual rygrass toxicity (ARGT)	Crown rot	
	Oat attacking strain of take-all	

9.1 Causes of cereal diseases

Cereal diseases are caused by fungi, viruses, bacteria and nematodes.

9.1.1 Fungi

Fungi and other pathogens (disease-causing organisms) often reduce grain yields by damaging green leaves, preventing them from producing the sugars and proteins

4 NSW DPI (2015) Winter crop variety sowing guide, Department of Primary Industries, New South Wales, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

5 GM Murray (2007) Review of diseases of oats for hay: current and future management, Part II: Identification and control options for the diseases of importance, Rural Industries Research and Development Corporation, Canberra, https://rirdc.infoservices.com.au/downloads/07-122

needed for growth. In other cases, they block or damage the plant's internal transport mechanisms, reducing the movement of water and sugars through the plant. Yields are also reduced when the pathogen diverts the plant's energy to reproducing more of the pathogen at the expense of plant growth or grain formation.

Fungi come in a diverse variety of forms. They spread by producing one or more types of spores, which may be carried by wind, through raindrop splashes or, in the case of smuts, by mechanical movement and mixing during harvest. Some fungi survive as spores in the soil, on seed or on plant debris, such as yellow leaf spot in wheat. Others survive as fine threads of growth inside plant debris or seed, and produce fresh spores in the following season. Spores are sometimes produced inside small fruiting bodies on infected plant tissue or stubble. Some diseases, such as rust, require continuous green host plants to survive from one season to the next.

9.1.2 Viruses

Viruses are invisible to the eye and even through a conventional microscope. Unlike other pathogens, viruses are totally dependent on the host for growth and multiplication. They cannot survive outside the plant, except in an insect or other animal that transmits the disease. They often damage plants by blocking their transport mechanisms. Barley yellow dwarf virus (BYDV) affects all of the cereals, with aphids as the vector for transmission of this disease.

9.1.3 Bacteria

Bacteria differ from fungi in that they do not form fine threads of growth, but instead multiply rapidly by continually dividing. They grow best under damp conditions and do not survive as well as fungi under dry conditions.

9.1.4 Nematodes

Nematodes are worm-like animals that cause various diseases in cereals. Most nematodes attack the plant roots or lower stems. An exception is the seed gall nematode, which causes cockles in wheat. Nematodes feeding on plants cause direct damage by reducing root area, damaging the transport mechanism or, in the case of the seed gall nematode, by replacing the grain with galls full of nematodes. [6] Cereal cyst nematode (CCN) is one such nematode that attacks wheat. See Section 8 Nematodes.

9.2 The disease triangle

Plant pathologists talk about the occurrence of disease in terms of the '*disease triangle*' (Figure 1)—an interaction of host, pathogen and environment. Alteration of any of these components of the disease triangle will influence the level of disease.

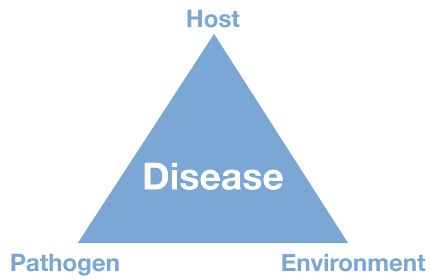


Figure 1: The disease triangle.

For disease to occur, there must be a susceptible host and a virulent pathogen, and the environment must be favourable. Following are some important examples of interactions of environmental conditions with diseases of grain crops.

[6] H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

More information

NSW DPI (2015) Winter crop variety sowing guide, Department of Primary Industries, New South Wales
http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

DAF Qld (2012) Disease management and weed control, Department of Agriculture and Fisheries, Queensland
https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/oats/diseases-and-weeds

- Low temperatures reduce plant vigour. Seedlings become more susceptible to *Pythium*, *Rhizoctonia* and other root and damping-off pathogens if they are emerging in soils below their optimum temperature.
- Pathogens have different optimum temperature ranges. For example, hatching in nematodes tends to occur over narrow soil temperature ranges, within a 10–25°C range and optimal at 20°C, whereas the take-all fungus *Gaeumannomyces graminis* var. *tritici* is more competitive with the soil microflora in cooler soils. This can lead to diseases being more prevalent in certain seasons or in different areas, such as wheat stem rust in warmer areas and stripe rust in cooler areas.
- Fungi such as *Pythium* and *Phytophthora*, which have swimming spores, require high levels of soil moisture in order to infect plants; hence, they are most severe in wet soils.
- Foliar fungal pathogens such as rusts require free water on leaves for infection (see Section 9.3). The rate at which most leaf diseases progress in the crop depends on the frequency and duration of rain or dew periods.
- Diseases that attack the roots or stem bases, such as crown rot, reduce the ability of plants to move water and nutrients into the developing grain. These diseases generally have more severe symptoms and larger effects on yield if plants are subject to water stress. [7]

9.3 Rusts

Rusts grow and reproduce only on living plants and must continually infect new hosts. They survive over summer by infecting wild oats and volunteer oats, and infect crops in the next season.

Seasons are at greater risk of a rust epidemic if:

- rust was present in the previous season
- summer and autumn rains allow wild or volunteer oats to grow over summer, harbouring and building up the rust ('green bridge')
- spring conditions are suitably wet [8]

Each factor depends on locality, so it is possible to assess rust risk in your locality.

Oat rusts have been very effective in breaking down resistance in commercially grown varieties of oats. As the pathotype of these diseases is constantly evolving, it is important that both growers and advisers are vigilant in the paddock, noting any cases of disease. Monitoring rust variability and forwarding samples to PBI Cobbity is a crucial part of using genetic resistance to combat these diseases.

PBI Cobbity is home to the Australian Cereal Rust Control Program (ACRCP), established in 1973, which is funded largely by the grains industry, through the GRDC. Pathogenicity surveys are conducted on an annual basis to monitor pathogenic change in the cereal rust pathogen populations. [9]

More information

Cereal rust services, Faculty of Agriculture and Environment, University of Sydney
http://sydney.edu.au/agriculture/plant_breeding_institute/cereal_rust/services.shtml

Growers and agronomists are encouraged to submit samples to the ACRCP for confirmation of rust identity and subsequent pathotype and virulence analyses. Samples should be sent in paper bags, not plastic, to:

Australian Rust Survey
University of Sydney
Reply Paid 88076
Narellan NSW 2567

7 UNE Agronomy of Grains Production course notes.

8 DAFWA (2016) Oats: leaf diseases, https://www.agric.wa.gov.au/oats/oats-leaf-diseases?page=0,1

9 University of Sydney (2012) Pathogenicity surveys, http://sydney.edu.au/agriculture/plant_breeding_institute/cereal_rust/pathogenicity_surveys.shtml

9.3.1 Stem rust (*Puccinia graminis* f. sp. *tritici*)

Figure 2: Stem rust in oats. (Photo: Robert Park)

Figure 3: Stem rust can occur on leaves, with spores being brick red. (Photo:Terry Hahn) [10]

10 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

Figure 4: Stem rust in oats rupturing the stem tissue. (Photo: Bob Rees) [11]

Stem rust is caused by the fungus *Puccinia graminis* f. sp. *tritici*. It can attack wheat, barley, rye and triticale.

Stem rust is similar in appearance to leaf rust and they can often be confused. However, stem rust is less important on grazing oats as it occurs later in the growing season, after most of the crop has been consumed. [12]

Stem rust can cause major yield loss in forage oat crops grown for seed or hay production. Stem rust has had the ability to cause significant economic damage (50–100% of yield). [13]

Stem rust produces reddish-brown spore masses in oval, elongated or spindle-shaped pustules on the stems and leaves, which appear about 7–10 days after infection. Unlike leaf rust, pustules erupt through both sides of the leaves. Ruptured pustules release masses of stem rust spores, which are disseminated by wind and other carriers. It is darker in colour and has tended to be more of a problem in milling oats.

Stem rust develops at higher temperatures than the other oat 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. Pustules can be seen after 10–20 days of infection.

Inoculum must be present for the disease to develop. Practising 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.

The disease is most common in high rainfall areas in large bulky crops.

Oat stem rust will not attack wheat and wheat stem rust does not attack oats. [14]

11 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

12 DAF Qld (2015) Forage oat variety guide 2015, https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

13 DAF Qld (2015) Forage oat variety guide 2015, https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

14 DAFWA (2016) Oats: leaf diseases, https://www.agric.wa.gov.au/oats/oats-leaf-diseases?page=0,1

9.3.2 Leaf or crown rust (*Puccinia coronata* var. *avenae*)

More information

DAF Qld (2015) Forage oat variety guide 2015 https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

GRDC (2015) Rust in oat: new challenges and international perspectives, Ground Cover Issue 116 May–June 2015 http://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-116-May-June-2015/Rust-in-oat-new-challenges-and-international-perspectives

DAFWA (2016) Oats: leaf diseases https://www.agric.wa.gov.au/oats/oats-leaf-diseases?page=0%2C1

University of Sydney (2015) Rust pathotype update, Cereal Rust Report 13(2), 17 August 2015 http://sydney.edu.au/agriculture/documents/pbi/cereal_rust_report_2015_13_2.pdf

Oat leaf rust is also known as crown rust. The word ‘crown’ refers to the shape of a type of spore produced by this fungus and is not related to the disease symptoms. It is closely related to leaf rust of wheat and barley, and has similar characteristics.

Crown rust has been a major problem in grazing oats, particularly in northern regions of the eastern Australian cereal belt.

The characteristic symptom is the development of round to oblong, orange to yellow pustules, primarily on leaves but also on stems and heads, appearing about 7–10 days after infection. The powdery spore masses in the pustules are readily dislodged. The pustule areas turn black with age. [15]

This disease is most severe under mild temperatures and moist conditions (e.g. in early autumn and early spring after wet, overcast conditions). This disease will build up very quickly on susceptible varieties. It will complete its life cycle and re-infect new leaves every 2–3 weeks. [16]

Oat leaf rust is potentially a very damaging disease, reducing both grain and forage yields, as well as forage quality and palatability. It does not infect wheat and wheat leaf rust does not infect oats. The fungus is carried over on volunteer oats and wild oats from season to season.

Control is similar to control for stem rust. Foliar fungicide registrations exist for control of this disease. When oats are grown for high-quality or export hay, early cutting should be considered before the disease builds up and causes obvious damage to leaves. [17]

The situation with stem rust resistance in oats is not much better than that for leaf rust, with pathotypes present in Australia that can overcome resistance in all cultivars.

In early 2013, the appearance of a new pathotype (strain) of crown rust on oats from north-eastern Australia was reported that could attack the previously resistant cultivar, Drover. This left Aladdin as the only oat cultivar with resistance to this disease. Unfortunately, in late 2014, yet another pathotype of crown rust was found that can infect Aladdin, meaning that there are now no grazing oat cultivars with good levels of resistance to crown rust. Options for controlling this disease in grazing oats in north-eastern Australia are now very limited. [18]

New research being funded by the GRDC is fast-tracking the identification and incorporation of minor gene or adult plant resistance to crown rust in Australian oat germplasm. Intensive efforts are also under way to find new sources of resistance to stem rust that can be used in the development of new cultivars.

Australian oat breeders are not alone in dealing with the challenges of rust. An oat rust forum was held at the University of Minnesota in the United States in February 2015 and brought together oat breeders, rust pathologists and industry stakeholders from North America and Australia. The meeting sought to develop a strategy for a community-wide approach to managing oat rust resistance and to set clear direction for funding agencies on how this effort should be supported. [19]

15 DAFWA (2016) Oats: leaf diseases, https://www.agric.wa.gov.au/oats/oats-leaf-diseases?page=0,2

16 DAF Qld (2015) Forage oat variety guide 2015, https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

17 DAFWA (2016) Oats: leaf diseases, https://www.agric.wa.gov.au/oats/oats-leaf-diseases?page=0,2

18 GRDC (2015) Rust in oat: new challenges and international perspectives, Ground Cover Issue 116 May–June 2015, http://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-116-May-June-2015/Rust-in-oat-new-challenges-and-international-perspectives

19 GRDC (2015) Rust in oat: new challenges and international perspectives, Ground Cover Issue 116 May–June 2015, http://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-116-May-June-2015/Rust-in-oat-new-challenges-and-international-perspectives

Figure 5: Leaf rust (Puccinia coronata var. avenae) may first appear in crops as 'hotspots' from an initial infection. Hotspots in early spring allow leaf rusts to build up to very severe levels by the end of the season. (Photo: DAFWA)

Table 4: Tracking the breakdown of crown rust resistance in oats

Cultivar	Year of release	Virulence first detected	Seedling
Culgoa II	1991	1996	*PcMortlock, PcCulgoa*
Bettong	1992	2001	*PCBett*
Cleanleaf	1992	1995	*Pc38, Pc39, Pc52*
Barcoo	1996	2001	*Pc39, Pc61, PcBett*
Graza 68	1997	1999	*Pc68*
Moola	1998	1999	*Pc68*
Gwydin	1999	2001	*Pc56*
Warrego	1999	1998	*Pc61+*
Nugene	2000	2005	*Pc48+*
Taipan	2001	2005	*Pc48+*
Volta	2003	2008	*Pc50, Pc68*
Genie	2008	2010	*Pc48, Pc56*
Drover	2006	2012	*Pc91*
Galileo	2006	?	Not tested
Qantom	2006	2008	*Pc50*
Dawson	2009	?	Not tested
Aladdin	2001	Not yet detected	*Pc50, Pc91*

Management of leaf rust

The frequency and severity of losses from leaf rust infection can be reduced by a range of management strategies:

1. Grazing management. Losses from leaf rust can be reduced by grazing or cutting rusted crops as early as possible once leaf rust is conspicuous below the top two leaves on each tiller and before the disease becomes severe. Given suitable conditions, it takes 7–14 days for a rust spore to infect and produce more spores. During this period, oat plants will normally produce several new leaves on each tiller. During active growth of the crop, the upper canopy may remain free of rust symptoms. Therefore, it is necessary to regularly inspect the crop to monitor rust occurrence. If leaf rust is obvious below the top two leaves on each stem, the crop should be grazed or cut, regardless of growth stage.

2. Cultivar selection. Select cultivars with good resistance to leaf rust. Although new varieties often become susceptible to rust after commercial release. Select high-yielding cultivars with late maturity. Recent forage oat variety releases are much higher yielding and much later to flower than the older dual-purpose varieties. Recent varieties will produce more forage yield over time, even when infected with leaf rust. Leaf rust is rarely a problem through the whole season, so late-flowering varieties will provide a longer grazing window and will recover multiple times from grazing.
3. Planting time. Avoid planting too early (before mid-March in Queensland) or too late (after June) to reduce the risk of young crops becoming infected. The conditions promoting leaf rust development are most likely to occur in late summer and autumn, and again in spring and early summer. Thus, sowing too early (before mid-March) or too late (after June) will increase the risk of young crops becoming infected and provide a source of inoculum. This cycle can be broken. For example, by delaying sowing until after mid-March, exposure to leaf rust is reduced early in the season and crops are still able to attain adequate growth before winter.
4. Crop hygiene. Control volunteer oat plants and wild oats. Both leaf and stem rust survive over summer between cropping seasons on volunteer oat plants, providing a continual supply of spores for fresh rust outbreaks each year.
5. Row width. Planting in wider rows may reduce the level of infection by lowering the humidity inside the crop canopy.
6. Nutrition. Maintaining good soil nutrition and adding extra nitrogen will minimise the effects of leaf rust. Nutrition requirements and fertiliser rates are similar to those recommended for wheat.
7. Fungicide. A number of fungicides are registered for control of leaf rust on forage oats in Queensland (Table 5) and New South Wales. Application of fungicide is more likely to be economically beneficial when infection levels are moderate to high (e.g. greater than 20% leaf area infected) or when crops are grown under irrigation and good dryland conditions. The use of fungicide is also beneficial in higher value crops grown for seed and hay. However, the application of fungicide to susceptible forage cultivars with low levels of leaf rust (0–10% leaf area infected) is unlikely to be economically beneficial, particularly when crops are growing under tough dryland conditions. All registered fungicides have a withholding period from grazing of 7–14 days after spraying. Fungicides should be applied as soon as there is sufficient leaf area to ensure good uptake of the active ingredient. This would normally be 7–14 days after grazing. [20]

Table 5: Commercially available foliar fungicides for control of rust disease in cereals in Australia 2015 [21]

Product name	Active ingredient	Company	Indicative cost	App rate (per ha)	App cost	Withholding period (grazing)	Registered for oats
Tilt 250SC	Propiconazole	Syngenta + Generic	$14/L	500 mL	$7/ha	7 days	Yes
Folicur 430SC	Tebuconazole	Bayer + Generic	$13/L	290 mL	$4/ha	14 days	Yes
Prosaro 420SC	Prothioconazole +Tebuconazole	Bayer	–	300 mL	–	14 days	Yes
Tilt Xtra	Propiconazole + Cyproconazole	Syngenta	$46/L	500 mL	$23/ha	21 days	No
Amistar Xtra	Azoxystrobin + Cyproconazole	Syngenta	$54/L	800 mL	$43/ha	21 days	No

20 DAF Qld (2015) Forage oat variety guide 2015, https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

21 DAF Qld (2015) Forage oat variety guide 2015, https://www.daf.qld.gov.au/__data/assets/pdf_file/0004/61969/forage-oat-variety-guide.pdf

Figure 6: *Close-up of leaf rust on leaves. (Photo: DAFWA)*

Figure 7: *Leaf rust in oats. (Photo: Bob Rees)* [22]

22 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

Figure 8: Leaf rust in oats. (Photo: Hugh Wallwork) [23]

Figure 9: Leaf rust in oats. (Photo: Hugh Wallwork) [24]

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GRDC (2015) Rust in oat: new challenges and international perspectives, Ground Cover Issue 116 May–June 2015 http://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-116-May-June-2015/Rust-in-oat-new-challenges-and-international-perspectives

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23 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

24 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

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Pacific Seeds (nd) Winter Forage https://www.pacificseeds.com.au/products/winter-forage.html

DAFWA (2016) Oats: leaf diseases https://www.agric.wa.gov.au/oats/oats-leaf-diseases?page=0%2C2

University of Sydney (2015) Rust pathotype update, Cereal Rust Report 13(2), 17 August 2015 http://sydney.edu.au/agriculture/documents/pbi/cereal_rust_report_2015_13_2.pdf

University of Sydney (2013) New oat crown rust pathotype with virulence for PC91, Cereal Rust Report 11(1), 8 February 2013 http://sydney.edu.au/agriculture/documents/pbi/cereal_rust_report_2013_vol_11_1.pdf

IPM (1989) Crown rust of oats, Report on Plant Diseases No. 109, Integrated Pest Management, July 1989 http://ipm.illinois.edu/diseases/series100/rpd109/

Figure 10: Black spores are produced late in the season. (Photo: Hugh Wallwork) [25]

9.4 *Barley yellow dwarf virus*

Symptoms of *barley yellow dwarf virus* (BYDV) can be confused with those caused by nutrient deficiencies, waterlogging or other plant stresses that cause yellowing, reddening and striping of leaves. Leaf symptoms differ between wheat, oats and barley. The severity depends on the age of the plant at infection, environmental conditions, the virus present and the cereal variety involved. [26]

In oats, the symptoms of BYDV infection are very striking. Most varieties develop reddening (crimson-pink) of the leaves from the tips down, which sometimes begins as blotching, especially on older leaves. Young leaves often have yellow stripes. However, some varieties only develop a yellow or orange coloration. Stunting, an increase in sterile tillers or abortion of florets result in low grain yields and shrivelled grain. As for wheat and barley, the effect of this virus is greatest in early-infected plants. [27]

Oats affected as seedlings may show additional symptoms of severe stunting, increased tillering and floret abortion. Infection after tillering causes a characteristic 'reddening' of later emerging leaves, and tip-reddening and death of older leaves. [28]

Distribution of infection within the paddock is as for all viruses, that being patchy, but in some cases the whole crop may show symptoms.

Aphids are the vector or vehicle of transmission of the disease (see Section 7. Insects).

Using the following control methods, among others, lessens the severity of the disease:

- Sow resistant varieties.
- Use an appropriate seed dressing that has an effect on aphids.
- Use an insecticide in-crop if aphid numbers are high.
- Sow to avoid the peak period of aphid activity.

25 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

26 DAFWA (2015) Managing Barley yellow dwarf virus and Cereal yellow dwarf virus in cereals, https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals?page=0,1

27 DAFWA (2015) Managing Barley yellow dwarf virus and Cereal yellow dwarf virus in cereals, https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals?page=0,1

28 DAFWA (2016) Oats: leaf diseases, https://www.agric.wa.gov.au/oats/oats-leaf-diseases?page=0,3

Figure 11: Barley yellow dwarf virus in oats. (Photo: Hugh Wallwork) [29]

Figure 12: Barley yellow dwarf virus in oats, showing sterility (blasting) at the stem base. (Photo: Terry Hahn) [30]

Figure 13: Stunting occurs when seedlings are infected. (Photo: Andrew Barr) [31]

29 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

30 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

31 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

More information

DAFWA (2015) Managing barley yellow dwarf virus and cereal yellow dwarf virus in cereals https://www.agric.wa.gov.au/barley/managing-barley-yellow-dwarf-virus-and-cereal-yellow-dwarf-virus-cereals

DAFWA (2016) Oats: leaf diseases https://www.agric.wa.gov.au/oats/oats-leaf-diseases?page=0%2C3

Figure 14: Reddening of oat leaves from BYDV infection. (Photo: DAFWA)

9.5 Rhizoctonia

Rhizoctonia root rot is an important disease of cereals in both the southern and western regions of the Australian grain belt. This is especially the case in the lower rainfall zones and on lighter soils. Yield losses in crops affected by bare patches can be over 50% and crops with uneven growth (Figure 15) may lose up to 20%.

In cereals, oats are most tolerant, followed by triticale, wheat and then barley, which is the most intolerant.

The disease is caused by *Rhizoctonia solani* AG8, a fungus that grows on crop residues and soil organic matter and is adapted to dry conditions and lower fertility soils.

The fungus causes crop damage by pruning newly emerged roots (spear-tipped roots), which can occur from emergence to crop maturity.

The infection results in water and nutrient stress to the plant, as the roots have been compromised in their ability to translocate both moisture and nutrients.

Figure 15: Above-ground symptoms of crop unevenness (left) are seen when rhizoctonia damages crown roots, even when seminal roots (right) escape the infection.

Management of rhizoctonia requires an integrated approach to reduce inoculum and control infection and impact on yield.

Rhizoctonia inoculum levels will be greatest following cereal planting, particularly barley. Grass-free canola is the most effective but legumes can also help reduce inoculum loading.

Disturbance below the seed at sowing promotes rapid root growth away from the rhizoctonia and disrupts hyphal networks. The ideal depth is 5–10 cm.

Fungicides applied through in-furrow liquid banding can provide useful suppression of rhizoctonia disease. Herbicides that slow root growth can exacerbate the problem.

Rhizoctonia disease is often a problem in low-fertility, sandy or calcareous soils of southern and western Australia. [32]

Table 6: Management of rhizoctonia disease in cereal crops

Year 1 crop (Sept-Nov)	Summer (Dec-April)	Season break (April-May)	Year 2 crop (May-August)
Check for inoculum build-up	*Facilitate inoculum decline*	*Select appropriate crop*	*Manage infection and disease impact through management practices*
• Paddocks can often be identified in the previous spring by estimating the area of bare patches and/or zones of uneven growth during spring – verify that poor plant growth is due to *Rhizoctonia* disease	• In wet summers, early weed control will reduce inoculum. In dry summers, inoculum levels do not change • Adopt practices that prolong soil moisture in the upper layers (e.g. stubble retention and no cultivation) which helps maintain higher microbial activity • Consider soil testing for pathogen inoculum level (PreDicta B™ test in Feb-March), to identify high disease risk paddocks, if disease is not confirmed in the previous cereal crop, especially if planning to sow cereals back on cereals	• Select a non-cereal crop (e.g. canola or pulses) if you want to reduce inoculum levels • Remove autumn 'green bridge' before seeding with good weed control	• Sow early; early-sown crops have a greater chance of escaping infection • Use soil openers that disturb soil below the seed to facilitate root growth – knife points reduce disease risk compared to discs • Avoid pre-sowing SU herbicides, • Supply adequate nutrition (N, P and trace elements) to encourage healthy seedling growth • Avoid stubble incorporation at sowing to minimize N deficiency in seedlings • Consider seed dressings and banding fungicides to reduce yield loss • Remove grassy weeds early • Apply nutrient/trace elements, foliar in crop, if required

9.6 Crown rot (*Fusarium graminearum*)

Crown rot is caused primarily by the fungi *Fusarium pseudograminearum* and/or *F. culmorum*. It is hosted by all winter cereals and many grass weeds. The crown rot fungi can survive for many years as mycelia inside infected plant residues. Cereal-on-cereal cropping programs and stubble retention can increase crown rot levels.

Major yield losses occur when disease levels are high and there is moisture and/or evaporative stress during grain filling. Yield loss can be up to 90% in durum and 50% in bread wheat or barley with increased screening.

Oat crops are considered 'symptomless hosts' of crown rot that may contribute to the maintenance of inoculum.

CSIRO investigated the incidence of *Fusarium graminearum* Group 1 (infection, stem colonisation) and crown rot in three-year crop sequences of one or two years of barley, oats or mown oats, followed by wheat, compared with three years of wheat.

32 GRDC (2016) Rhizoctonia Tips and Tactics–Southern Region. Root damage causes yield loss in cereals.

Seed was sown into the stubble of the previous crop and stubble production estimated for each cereal treatment. Plants of each cereal were infected by the crown rot pathogen. Oats were found to be susceptible to infection but did not express symptoms of crown rot in the two years of the trial.

The overall mean incidence of infected plants increased from 12% in 1987 to 81% in 1989. The various treatments did not significantly reduce the incidence of infected wheat plants in November of the final year. The incidence of crown rot of wheat in 1989 was greatest after two prior wheat crops and lowest after one or two years of mown oats.

The three species produced a similar amount of straw by weight; however, mown oats produced significantly less. Oat straw decomposed more rapidly than that of other cereals in controlled conditions. [33]

See CSIRO: 'Effect of rotation with barley and oats on crown rot of wheat in the northern wheat belt of New South Wales' at http://www.publish.csiro.au/paper/EA9950765.htm.

9.7 Bacterial blights

Blights survive on seed and crop debris. They are spread by rain splash, leaf contact and insects, especially aphids. Moist weather conditions favour development and spread from crop debris or seed coat to seedlings and then from one leaf to the next. Symptoms often develop after frost. A period of warm, dry weather stops the spread. Heavy infection with either disease leads to withering and death of leaves, often starting from the tip. [34]

These diseases can reduce the appearance of hay and hence downgrade its value.

Using these control measures can help avoid blights:

- Avoid susceptible varieties, referring to your local state variety sowing guide for resistance ratings.
- Use seed from uninfected crops.
- Destroy infected oat stubbles.

9.7.1 Stripe blight (*Pseudomonas syringae* pv. *striafaciens*)

Bacterial stripe blight is the main blight disease in oats. It causes spots on leaves and leaf sheaths, without the halos produced by halo blight. The spots lengthen and form water-soaked patches and then brown stripes, which often have narrow yellow margins. The lesions join, forming irregular blotches. If the stripe occurs in the boot, the floret inside may appear rotten and stained. Emergent florets appear mottled brown to white and may be sterile. [35]

The bacteria multiply in huge numbers in the stripes and bacterial slime can sometimes occur on the lesions. When a lesion is cut transversely and the leaf put on a microscope slide, a faint white slime can sometimes be seen coming from the leaf veins. Bacterial ooze from veins is easily observed under a microscope. [36]

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33 KE Nelson, LW Burgess (1995) Effect of rotation with barley and oats on crown rot of wheat in the northern wheat belt of New South Wales, Australian Journal of Experimental Agriculture 35(6) 765–770, http://www.publish.csiro.au/paper/EA9950765.htm

34 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

35 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

36 GM Murray (2007) Review of diseases of oats for hay: current and future management, Part II: Identification and control options for the diseases of importance, Rural Industries Research and Development Corporation, Canberra, https://rirdc.infoservices.com.au/downloads/07-122

Figure 16: Stripe blight (bacterial blight) in oats. (Photo: Hugh Wallwork) [37]

Figure 17: Stripe blight (bacterial blight) in oats with head sterility. (Photo: Hugh Wallwork) [38]

9.7.2 Halo blight (*Pseudomonas syringae* pv. *coronafaciens*)

Halo blight causes light green or buff-coloured, oval-shaped spots surrounded by a pale halo with a water-soaked appearance up to 10 mm in diameter. The centre of the spots changes to a straw or brown colour, and a yellow-green halo develops in the surrounding leaf. Later the patches turn brown, join together and form irregular blotches. [39]

37 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

38 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

39 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

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Figure 18: Halo blight (bacterial blight) in oats. (Photo: Bob Rees) [40]

Figure 19: Halo blight (bacterial blight) in oats, showing water-soaked halo. (Photo: Hugh Wallwork) [41]

9.8 Other diseases

9.8.1 Red leather leaf (*Spermospora avenae*)

The first recorded incidence of this disease was in Victoria in 1978. The disease is characterised by small lesions with light centres that are surrounded by a bright-red or

[40] H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

[41] H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

red-brown colour that may extend along a large area of the leaf. The central green area later becomes necrotic and frequently disintegrates to leave a ragged hole surrounded by a reddish-brown border. Leaf margins and tips can die prematurely. Infected leaves can become stiff, may be slightly rolled and will assume a leathery appearance. Plants may be slightly stunted. [42]

In severe cases, whole fields can take on a brilliant red colour in winter, as reported in the Pacific north-west of the United States.

Survival of the fungus is in plant debris. The disease occurs in high-rainfall areas with high humidity. [43]

The severity of the disease is not known, although large yield losses are likely where the foliage is severely damaged.

Control measures:

- Avoid susceptible varieties in high-risk areas.
- Use fungicides that have proven to suppress the spread of this disease. [44]

Figure 20: Red leather leaf in oats. (Photo: Andrew Barr) [45]

42 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

43 GM Murray (2007) Review of diseases of oats for hay: current and future management, Part II: Identification and control options for the diseases of importance, Rural Industries Research and Development Corporation, Canberra, https://rirdc.infoservices.com.au/downloads/07-122

44 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

45 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

Figure 21: Red leather leaf in oats. (Photo: Hugh Wallwork) [46]

9.8.2 Septoria blotch (*Phaeosphaeria avenaria*)

Septoria blotch gets its name from that given to the form of the fungus seen growing on oat leaves. Septoria blotch is the most common oat disease in Western Australia; it is less common in New South Wales and Queensland. It is most severe in early-sown crops in high-rainfall areas. Septoria blotch survives between growing seasons on oat stubble.

This disease may cause up to 50% yield loss and crop lodging in extreme cases but losses of around 10% are more common in high-rainfall areas. Tall or slow-maturing oats are less likely to be affected by the disease than short (dwarf) or fast-maturing varieties. [47]

The disease is caused by the fungus *Parastagonospora avenaria* f.sp. *avenaria* (synonym: *Phaeosphaeria* or *Stagonospora avenae* f.sp. *avenaria*). It is not one of the septoria diseases of wheat, which are caused by different species. [48]

The disease is also known as speckled blotch and septoria black stem. It can occur on any aboveground part of the oat plant.

It reduces yield, quality and appearance of hay. Septoria is more likely to be a problem in early-sown susceptible crops that are exposed to frequent rainfall, which disperses rain-splashed spores. [49]

Septoria blotch affects leaves, inflorescence and seed. Leaf lesions are small, dark brown to purple, and oval to elongated. They are restricted and distinct at first but may enlarge to cover most of the leaf. They enlarge to light-brown or dark-brown blotches up to 2 cm, with surrounding yellow areas. They can coalesce and kill the entire leaf.

[46] H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

[47] DAFWA (2016) Oats: leaf diseases, https://www.agric.wa.gov.au/oats/oats-leaf-diseases

[48] GM Murray (2007) Review of diseases of oats for hay: current and future management, Part II: Identification and control options for the diseases of importance, Rural Industries Research and Development Corporation, Canberra, https://rirdc.infoservices.com.au/downloads/07-122

[49] DAFWA (2016) Oats: leaf diseases, https://www.agric.wa.gov.au/oats/oats-leaf-diseases

Infections on the leaf sheath can grow onto the stem to produce greyish-brown or shiny black lesions. Severely affected tillers can lodge.

Dark-brown blotches can develop on the florets and seed. Small brown to black fruiting bodies (pycnidia) develop in lesions. Sometimes these are prominent but often are difficult to see, even with a magnifying lens. [50]

The fungus produces its sexual stage in fruiting bodies, called perithecia, on oat stubble in autumn and releases wind-borne ascospores when wetted by rain or heavy dew in autumn and winter. The ascospores can travel long distances by wind to infect young oat plants. Ascospores are probably the chief source of primary inoculum, although the epidemiology has not been studied under Australian conditions.

Infections in the crop produce a second type of fruiting body, the pycnidia, in the leaf lesions. Asexual spores called pycnidiospores ooze from pycnidia in wet weather and are spread short distances (< 1 m) by rain splash. Pycnidiospores are the secondary inoculum; their number and the number of generations of the asexual stage in the crop determine the severity of the epidemic. Frequent rain favours cycles of infection by pycnidiospores.

These are the current recommendations for control of septoria blotch:

- Sow partially resistant varieties.
- Avoid sowing early in high-rainfall areas.
- Burn or bury infested oat straw when oat crops are to be sown nearby.
- Do not sow susceptible oats continuously in the same or neighbouring paddocks.

Foliar fungicide registrations exist for control of this disease. [51]

Figure 22: Septoria blotch in oats, showing the brown blotches surrounded by a yellow area. (Photo: Bob Rees) [52]

[50] GM Murray (2007) Review of diseases of oats for hay: current and future management, Part II: Identification and control options for the diseases of importance, Rural Industries Research and Development Corporation, Canberra, https://rirdc.infoservices.com.au/downloads/07-122

[51] GM Murray (2007) Review of diseases of oats for hay: current and future management, Part II: Identification and control options for the diseases of importance, Rural Industries Research and Development Corporation, Canberra, https://rirdc.infoservices.com.au/downloads/07-122

[52] H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

Figure 23: Sepotoria blotch in oats. (Photo: Hugh Wallwork) [53]

Figure 24: Sepotoria blotch in oats, showing lesions on stems that can lead to lodging. (Photo: Andrew Barr) [54]

9.8.3 Loose smut (*Ustilago avenae*) and covered smut (*Ustilago hordei*)

Loose smut and covered smut in oats are both externally seed-borne diseases with similar symptoms, and are difficult to distinguish in the field. Both diseases are managed in the same way. After sowing, spores on the seed surface germinate and infect the emerging seedling. The fungus grows without symptoms within the plant and identification of infected plants is difficult prior to head emergence.

Affected plants may be slightly taller and heads emerge earlier than the main part of the crop. Each spikelet, including the chaff, is replaced with a spore mass that is at first covered with a fine white or grey membrane. This membrane soon bursts, releasing the spores to contaminate healthy heads and leaving a bare stalk or rachis on the infected plant. [55]

53 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

54 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

55 DAFWA (2015) Smut and bunt diseases of cereal. https://www.agric.wa.gov.au/autumn/smut-and-bunt-diseases-cereal-biology-identification-and-management?page=0,1

The disease can be spread by air-borne spores that lodge in healthy glumes, where they remain dormant until seeding or else grow into the hulls or seed coats and remain inactive until seeding.

Infection is favoured by moist conditions during flowering, with temperatures of 15–25°C. Early sowing into a warm seedbed has often been associated with smut outbreaks. [56]

Smuts have exceeded 50% incidence in susceptible varieties when no control is applied. [57]

Control measures:

- Low cost by seed treatments.
- Do not sow seed harvested from crops with obvious smut.
- Avoid growing susceptible varieties.

Figure 25: Damaged oat floret from smut infestation. (Photo: Hugh Wallwork) [58]

[56] H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

[57] GM Murray (2007) Review of diseases of oats for hay: current and future management, Part II: Identification and control options for the diseases of importance, Rural Industries Research and Development Corporation, Canberra, https://rirdc.infoservices.com.au/downloads/07-122

[58] H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

Figure 26: Smut in oats. (Photo: Hugh Wallwork)

Figure 27: Smut spores at flowering infect nearby heads. (Photo: Margaret Evans) [59]

9.8.4 Ergot (*Claviceps purpurea*)

Ergot is a fungal infection that replaces grass seeds with a fungal resting body. These can contain extremely poisonous chemicals that can kill animals.

Ergot can come from oat florets or from grass weeds in the oat crop. Ergot is more a problem for grain crops than for hay production. Because ergot is similar in size to seed, they will contaminate grain harvested from crops.

59 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

Symptoms include honeydew (sticky exudate), which develops in heads of grasses shortly after head emergence. A dark purple to black ergot develops in some florets in place of the normal seed. Ergots are roughly the same shape as the seed of the host plant but are 1.5–4 times the size, usually extending prominently out of the floret.

The causal fungus survives in and on soil for several years. These germinate in spring to produce a small fruiting body that releases air-borne spores (ascospores) that can infect nearby grass florets. Ryegrass seems to be particularly susceptible to ergot. [60]

Figure 28: Ergot in oats. (Photo: Ken Holden) [61]

60 GM Murray (2007) Review of diseases of oats for hay: current and future management, Part II: Identification and control options for the diseases of importance, Rural Industries Research and Development Corporation, Canberra, https://rirdc.infoservices.com.au/downloads/07-122

61 H Wallwork (2000) Cereal leaf and stem diseases. GRDC.

SECTION 10

Plant growth regulators and canopy management

More information

DAFWA (2015): Oats: fertilisers and plant nutrition

GRDC: Disease management and crop canopies

GRDC (2013) Moddus Evo: Controlling plant growth for reduced lodging and improved yields

A Tam, S Mooney, P Berry (2004) The Effect of Lodging in Cereals on Morphological Properties of the Root-Soil Complex, SuperSoil 2004: 3rd Australian New Zealand Soils Conference

B Dear, A Kaiser, J Piltz (2005) Yield and digestibility of legume and oat forages, Primefacts Nov. 2005

10.1 Canopy management

Canopy management is the manipulation of the green surface area of the crop canopy to optimise crop yield and inputs. It is based on the premise that the crop's canopy size and duration determine its photosynthetic capacity and therefore its overall grain productivity.

Adopting canopy-management principles and avoiding excessively vegetative crops may enable growers to achieve a better match of canopy size with yield potential, as defined by the available water. Other than sowing date, plant population is a starting point for the grower to influence the size and duration of the crop canopy. [1]

The concept of canopy management has been primarily developed in Europe and New Zealand—both different production environments from those typically found in most grain-producing regions of Australia.

Canopy management includes a range of crop-management tools for crop growth and development, to maintain canopy size and duration, thereby optimising photosynthetic capacity and grain production. One of the main tools available to growers to manage the crop canopy is the rate and timing of applied fertiliser nitrogen (N). [2]

10.1.1 Importance of canopy management

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

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

2 G McMullen (2009) Canopy management in the northern grains region—the research view. Northern Grains Alliance, July 2009, http://www.nga.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf

enough stored water-soluble carbohydrates to fill the grain. Therefore, grain size and yield decrease.

To attain maximum yield, it is important to achieve a balance between biomass and resources. The main factors that can be managed are:

- plant population
- row spacing
- inputs of N
- sowing date
- weed, pest and disease control
- plant growth regulation with grazing or specific plant growth regulator products

Of these, the most important to canopy management are N, row spacing and plant population. [3]

10.1.2 Grazing cereal crops as a management tool

Well-managed, dual-purpose cereals provide producers with an opportunity for increased profitability and flexibility in mixed farming systems by enabling increased winter stocking rates and generating income from forage and grain. Typically, these crops are earlier sown, longer season varieties that provide greater DM production for grazing. Research has shown that to avoid grain-yield penalties, stock must be removed from cereals before the end of tillering (GS30). However, the timing and intensity of grazing during the season can incur yield penalties, particularly when grazing pressure is high and late in the grazing period.

More information

GRDC Update Papers: Grazing wheat and barley—impacts on crop management, lodging and grain yield

Grazing can sometimes be beneficial to grain production by reducing lodging; in seasons with dry springs, grazing can increase grain yields by reducing water use in the vegetative stages, leaving more soil water for grainfill. The challenge for growers is to find the balance of optimising DM removal without compromising grain production. [4]

10.1.3 Key stages for disease control and canopy management

The optimum timing for foliar-applied fungicides in cereals is from the start of stem elongation to ear emergence (GS30–59).

The optimum time for spraying a fungicide to protect a leaf is at full emergence. Leaves not emerged at the time of application will not be properly protected. Leaves will usually be free from foliar disease on emergence. The time between when the disease spores land on the leaf and when an infection point is visible is called the latent period or latent phase. This period is temperature driven and differs between diseases. It can be as short as seven days for diseases such as powdery mildew. [5]

More information

GRDC Driving Agronomy Podcasts: Disease management and crop canopies

It was common 5–10 years ago to make decisions on fungicide applications for foliar disease based on thresholds of infection. These thresholds varied from 1% to 5% of plants infected. However, growers and advisers found that in the paddock it was difficult to calculate when this disease threshold had been reached, not least because of the sporadic nature of the initial foci of the disease. In addition, by the time growers realised that the threshold had been reached and carried out the spray operation, the crops were badly infected. When crops that are badly infected with stripe rust are treated with fungicides, the control is poor because fungicides work better as protectants than as curatives.

[3] 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

[4] GRDC (2102) Grazing wheat and barley—impacts on crop canopy management. GRDC Update Papers, 23 March 2012, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Grazing-wheat-and-barley-impacts-on-crop-canopy-management-lodging-and-grain-yield

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

SECTION 11

Crop desiccation/spray out

Not applicable for this crop.

SECTION 12

Harvest

Australian oats are harvested during October to December by direct heading as soon as the crop is ripe. [1]

In some regions there may be long periods of unsuitable weather conditions in which the harvesting of dry grain may not be possible. This may cause considerable delays to the harvesting operation and increase the risk of head loss or grain being discoloured by early summer rains. Oats can shatter or shell out more readily than any other cereal crops.

To reduce harvesting delays the grain can be direct harvested at a moisture content above 12 per cent (%) and then placed under aeration to maintain quality or passed through a grain dryer to reduce its moisture content to a level that can be safely stored. The cost of aeration or drying needs to be weighed up against the value of the grain.

Prioritise the varieties that are likely to shed or lodge. Delays can lead to significant lodging and shedding due to crop movement in the wind.

Consider management of stubble for the following crop (straw length and spreading) and collection of weed seeds for herbicide resistance management in an effort to reduce the weed burden for the following crop

Care must be taken in harvesting milling varieties to minimise the amount of dehulled grain. Hull-less oats are susceptible to harvest damage, as such adjustment to the harvest timing is therefore critical. [2]

Figure 1: Harvesting oats in NSW. (Photo: AM Mostead)

[1] AEGIC. Australian Grain Note: Oats, http://www.aegic.org.au/media/23324/140214 Oats Note.pdf

[2] DAFWA (2015) Oats: harvesting, swathing and grain storage, https://www.agric.wa.gov.au/oats/oats-harvesting-swathing-and-grain-storage?page=0%2C2

12.1 Lodging

Lodging of oats is a problem, particularly in tall varieties and in high rainfall zones or high Nitrogen situations. The heavy mat of stems that is formed in a lodged crop can result in delayed ripening due to reduced airflow, increased shading and higher soil moisture.

Lodged crops should be harvested panicles first (one direction only) to ensure maximum pickup. Excessive dehulling needs to be avoided as dehulled oats are more likely to become rancid and delivery specifications limit the number of dehulled oats in a sample. Ensuring correct speed and clearance is important to avoid excessive dehulling. [3]

12.1.1 Delaying harvest

Every day a crop stands in the paddock it is exposed to ongoing yield loss and quality degradation (Figure 2). Yield is reduced by shedding, head loss and general exposure to the elements. This is measured as a loss of yield each day in dry matter (DM).

Most growers have also experienced some form of grain quality loss due to delayed harvest. Oats can become discoloured or de-hullled and fungal growth reduces the end use possibilities.

These factors can combine to result in heavy discounts from a crop's net return. Time increases these risks, and ongoing exposure to moisture will eventually cause yield loss and development of one or more of these quality defects (Figure 2).

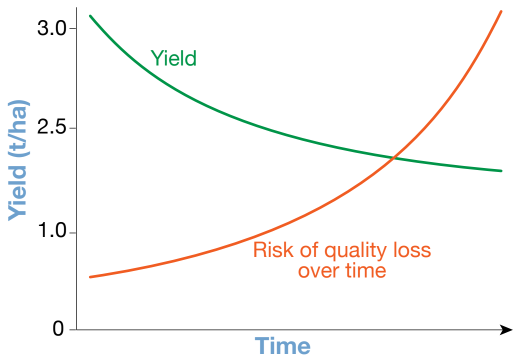


Figure 2: Yield and risk of quality loss over time

12.2 Fire prevention

With research showing an average of 12 harvesters are burnt to the ground every year in Australia, agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses (Figure 3).

[3] DAFWA: Oats: harvesting, swathing and grain storage. https://www.agric.wa.gov.au/oats/oats-harvesting-swathing-and-grain-storage?page=0%2C2

Figure 3: Keeping headers clean can reduce the risk of fire. (Photo: Rebecca Thyer.)

Key points:

- Most harvester fires start in the engine or engine bay.
- Other fires are caused by failed bearings, brakes and electricals, and rock strikes.
- Regular removal of flammable material from the engine bay is urged. [4]

More information

http://www.graincorp.com.au/_literature_141941/Oats_GrainCorp_Standards_2015-16

12.3 Receival standards

For up to date information on oats trading standards from Grain Trade Australia, visit http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/2015_2016/Section%2002%20-%20Oats%20Trading%20Standards%20201516%20Final.pdf

More information

GRDC Weed Webinars: Beginners guide to harvest weed seed control

https://www.agric.wa.gov.au/oats/oats-weeds-and-integrated-weed-management

12.4 Harvest weed seed management (HWSM)

Targeting weed seeds at harvest is a pre-emptive action against problematic populations of annual weeds. Our most damaging crop weeds—annual ryegrass, wild radish, wild oats and brome grass—are all capable of establishing large, persistent seedbanks. Thus, if annual weeds are allowed to produce seed that enters the seedbank, the cropping system will inevitably be unsustainable.

Fortunately, seedbank decline is rapid for these weed species, with annual seed losses of 60–80%. Without inputs, a very large seedbank (>1000 seed/m^2) can therefore be reduced to a very modest one (<100 seed/m^2) in just 4 years. A small seedbank of weeds allows easier and more effective weed control with reduced risk of development of herbicide resistance. Effective weed management in productive cropping systems is thus reliant on preventing viable seed from entering the seedbank. Several systems developed over the past three decades target the weed-seed-bearing chaff fraction during harvest. [5]

4 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

5 M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control

12.4.1 Intercepting annual weed seed

Western Australia has been leading the way in the fight against resistant weeds, where high frequencies of herbicide-resistant weed populations have been driving farming practices for the last decade. Techniques have been developed targeting weed seeds during harvest, and these techniques are now being adopted in the eastern states. At harvest, much of the total seed production for the dominant weed species is retained above harvester cutting height (Table 1). Additionally, for some of these species such as wild radish, high levels of seed retention are maintained over much of the harvest period (Figure 4). Therefore, the collection and management of the weed-seed-bearing chaff fraction can result in significant reductions in population densities of annual weeds.

Table 1: Proportion of total seed production retained above a low harvest cutting height (15 cm)

Species	Seed retention above 15 cm (%)
Annual ryegrass	88
Wild radish	99
Brome grass	73
Wild oats	85

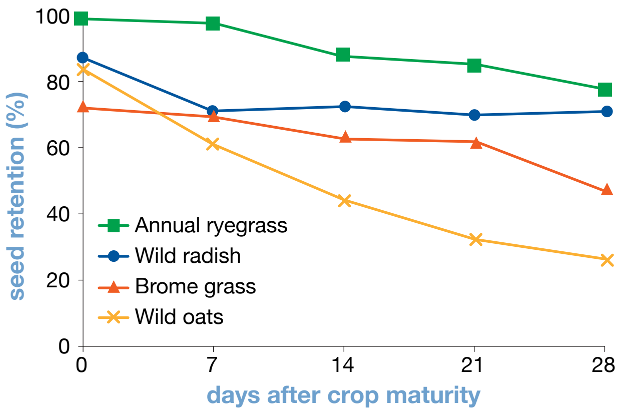


Figure 4: Seed retention above a harvest height of 15 cm over the first 4 weeks of harvest for the major weeds of Western Australian wheat crops.

Western Australian farmers have driven the development of several systems such as windrow burning, and chaff carts that reduce inputs of annual ryegrass, wild radish, wild oats and brome grass into the seedbank. The adoption of these systems has been critical for the continuation of intensive cropping systems across Australia. [6]

More information

IWM Section 4: Tactics

A key strategy for all harvest weed-seed control operations is to maximise the percentage of weed seeds entering the header. This means harvesting as early as possible before weed seed is shed, and harvesting as low as is practical (e.g. 'beer-can' height).

12.4.2 Burning of narrow windrows

During traditional, whole-paddock stubble burning, the very high temperatures needed for weed-seed destruction are not sustained for long enough to kill most weed seeds, in particular wild radish. 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. Stubble cover is also retained across the paddock, resulting in less erosion and greater moisture retention

6 M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control

Establishing narrow windrows suitable for autumn burning is achieved by attaching chutes to the rear of the harvester to concentrate the straw and chaff residues as they exit the harvester (Figures 5 and 6). This concentration of residue increases the seed-destruction potential of residue burning. With more fuel in these narrow windrows, the residues burn hotter than standing stubbles or even conventional windrows. Weed-seed kill levels of 99% for both annual ryegrass and wild radish have been recorded from the burning of wheat, canola and lupin stubble windrows. [7]

Figure 5: Harvest in action—producing narrow chaff rows for burning in the following autumn. (Photo: A. Storrie)

Figure 6: Windrow burning. (Photo: Penny Heuston)

More information

GRDC: Narrow windrow burning in southern New South Wales

GRDC Report: Developments in stubble retention

IWM Section 4: Tactics

GRDC Videos

Weed seed bank destruction—windrow chute design

Weed seed bank destruction—Header setup and tips for narrow windrowing

Weed seed bank destruction—narrow windrow burning

Weed seed bank destruction—burning windrows safely

Weed seed bank destruction—nutrient losses: comparing chaff heaps with narrow windrows

Weed seed bank destruction—vary windrow placement to avoid potassium concentration

[7] M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control

12.4.3 Chaff carts

Figure 7: Chaff cart in action, WA. (Photo: Trent Butcher, ConsultAg)

Chaff carts are towed behind headers during harvest to collect the chaff fraction as it exits the harvester (Figure 7). Collected piles of chaff are then burnt the following autumn or used as a source of stock feed. [8]

The weed-seed collection efficiency of several commercially operating harvesters with attached chaff carts was evaluated by the Australian Herbicide Resistance Initiative (AHRI). Harvesters were found to collect 75–85% of annual ryegrass seeds and 85–95% of wild radish seeds entering the front of the header during the harvest operation. Collected chaff must be managed to remove weed seeds from the cropping system. Typically, this material is left in piles in the paddock to be burnt in the following autumn. In some instances though, chaff is removed from the paddock and used as a source of feed for livestock. [9]

More information

IWM Section 4: Tactics

GRDC Videos

Weed seed bank destruction—an integrated approach to weed management

Weed seed bank destruction—more efficient use of chaff carts

Weed seed bank destruction—wild radish seed

Weed seed bank destruction—burning chaff dumps

Weed seed bank destruction—seeing results from integrated weed management

12.4.4 Bale-direct systems

An alternative to the *in-situ* burning or grazing of chaff, the bale-direct system uses a baler attached to the back of the harvester to collect all chaff and straw material as it exits the harvester. As well as removing weed seeds, the baled material has an economic value as a livestock feed source. [10]

The bale-direct system was developed by the Shields family in Wongan Hills as a means of improving straw hay production. It consists of a large square baler directly attached to the harvester that collects and bales all harvest residues. A significant secondary benefit is the collection and removal of annual weed seeds. Studies by AHRI determined that ~95% of annual ryegrass seed entering the harvester was collected in the bales. [11]

8 GRDC. Section 6: Managing weeds at harvest. GRDC Integrated Weed Management Hub, http://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

9 M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control

10 GRDC. Section 6: Managing weeds at harvest. GRDC Integrated Weed Management Hub, http://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

11 M Walsh, S Powles (2007) Management strategies for herbicide-resistant weed populations in Australian dryland crop production systems. Weed Technology 21, 332–338, http://www.jstor.org/stable/4495856?seq=1#page_scan_tab_contents

As well as being an effective system for weed-seed removal, the baled material can have a substantial economic value as a feed source. However, as with all baling systems, consideration must be given to nutrient removal. [12]

For the story of development of header-towed bailing systems, see: http://www.glenvar.com/.

Figure 8: Bale direct machine at Kellie Shield's "Gunwarrie" Frankland River. (Photo: Penny Heuston)

More information

IWM Section 4: Tactics

12.4.5 Chaff grinding—the Harrington Seed Destructor

Processing of chaff sufficient to destroy any weed seeds that are present during the harvest operation is the ideal system for large-scale Australian conservation cropping systems. Rendering weed seeds non-viable as they exit the harvester removes the need to collect, handle and/or burn large volumes of chaff and straw residues. Because of the importance and potential industry benefits of this process, there has been substantial interest in the development of an effective system.

Ray Harrington, a progressive farmer from Darkan, Western Australia, invented and developed the Harrington Seed Destructor (HSD), a cage-mill-based system attached to the back of the harvester that processes chaff during harvest.

More information

IWM Section 4: Tactics

The HSD system comprises a chaff-processing cage mill, and chaff and straw delivery systems. The retention of all harvest residues in the field reduces the loss and/or banding of nutrients and maintains all organic matter to protect the soil from wind and water erosion, as well as reducing evaporation loss compared with windrow burning, chaff carts and baling. [13]

GRDC Videos

IWM—Harrington Seed Destructor (3 videos)

Weed seed destruction—beer can height

Weed seed bank destruction—lessons learned—windrowing canola

Weed seed bank destruction—Spear grass (*Bromus* spp.) an emerging problem

Evaluation under commercial harvest conditions by AHRI has determined that the HSD will destroy ≥95% of annual weed seed during harvest. With the efficacy of the HSD system well established, its development has progressed to commercial production. [14, 15]

A new chaff grinder that is integrated into the back of the header is nearing commercial production stage. It has similar principles to the HSD and it was developed at the University of South Australia.

12 M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control

13 GRDC. Section 6: Managing weeds at harvest. GRDC Integrated Weed Management Hub, http://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

14 M Walsh, S Powles (2012) Harvest weed seed control. GRDC Update Papers, 12 April 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Harvest-weed-seed-control

15 de Bruin Engineering. Harrington Seed Destructor. Projects, De Bruin Engineering

More information

http://www.nufarm.com/Assets/28377/1/weedmasterDSTHay_Silage_v1.pdf

http://www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

12.5 Desiccation pre-hay cutting

With the registration of Weedmaster DST for desiccating hay pre-cutting, growers now have an option which reduces weed seed set and prevents re-growth of weeds and oats.

Desiccating 1-11 days pre-mowing delivers benefits including:

- Reducing weed seed set
- Preventing hay and weed re-growth
- Preserve soil moisture
- Maintain or improve hay quality

For some growers wheel tracks can be an issue for mowing but this is best managed by spraying in a different direction to the hay mower.

A 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

SECTION 13

Storage

An on-farm storage system designed for good hygiene that includes aeration and sealable silos for fumigation is essential for growers who wish to maximise their returns from cereal grains. Without sealable silos, growers could be contributing to Australia's problem of insect resistance to phosphine, the most common fumigant used in the Australian grain industry. Without aeration, growers risk excluding themselves from markets that will not accept chemically treated grain.

In conjunction with sound management practices, which include checking grain temperatures and regular monitoring for insect infestations, an on-farm storage system that is well designed and maintained and properly operated provides the best insurance a grower can have on the quality of grain to be out-turned.

Figure 1: Storage with aeration is important for protecting Australia's markets. (Photo: QDAFF)

Grain Trade Australia (GTA) stipulates standards for heat-damaged, bin-burnt, storage-mould-affected or rotten grain, all of which can result in the discounting or rejection of grain. GTA has nil tolerance to live, stored grain insects for all grades from milling grades to feed. [1]Effective management of stored grain can eliminate all of these risks to quality.

[1] Grain Trade Australia (2013) Wheat Standards, 2013/2014 season. GTA, August 2013.

In grain storages in Queensland, including central Queensland, and New South Wales, target grain temperatures of stored oats should be 20–23°C during summer and less than 15°C in winter. [2]

Grain temperatures of 20°C or less are considered cool. Lower temperatures maintain grain quality and reduce insect population growth [3]

More information

https://www.agric.wa.gov.au/oats/oats-harvesting-swathing-and-grain-storage?page=0%2C2

http://storedgrain.com.au/pest-control-guide-ns/

http://storedgrain.com.au/stored-grain-pests-id-ns/

13.1 How to store oats on-farm

According to the Kondinin Group National Agricultural Survey 2011, silos account for 79% of Australia's on-farm grain storage, compared with 12% for bunkers and pits and 9% for grain bags.

Aerated silos that can be sealed during fumigation are widely acknowledged as the most effective ways to store oats on-farm (Table 1). There is now an Australian standard (AS2628) for sealable silos that manufacturers in Australia can choose to use as a construction standard to ensure reliable fumigation results.

Table 1: Advantages and disadvantages of grain storage options

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	• Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects • Easily aerated with fans • Fabricated on-site or off-site and transported • Capacity from 15 t up to 3000 t • Up to 25 years plus service life • Simple in-loading and out-loading • Easily administered hygiene (cone base particularly) • Can be used multiple times in-season	• Higher initial investment required • Seals must be maintained • Requires an annual test to check gas-tight sealing
Non-sealable silo	• Easily aerated with fans • 7–10% cheaper than sealed silos • Capacity from 15 tonnes up to 3,000 tonnes • Up to 25–35 years of service life • Can be used multiple times in-season	• Grain in non-sealable silo cannot be fumigated for pest control — see phosphine label • Insect control options are limited, that is, protectants in eastern states and Dryacide in Western Australia.

2 P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014., GRDC Update, July 2013.

3 http://legacy.crcplantbiosecurity.com.au/program/post-harvest-integrity/project/crc50060-cool-grain-fumigation.html

Storage type	Advantages	Disadvantages
Grain storage bags	• Low initial cost • Can be laid on a prepared pad in the paddock • Provide harvest logistics support • Can provide segregation options • Are all ground operated • Can accommodate high-yielding seasons	• Requires purchase or lease of loader and unloader • Increased risk of grain damage beyond short-term storage (typically three months) • Limited insect control options, fumigation only possible under specific protocols • Requires regular inspection and maintenance which needs to be budgeted for • Aeration of grain in bags is not practical in most circumstances • Should be fenced off from domestic and native animals • Bags and grain 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 of bag
Grain storage sheds	• Can be used for dual purposes • 30 year plus service life • Low cost per stored tonne	• Aeration systems require specific design • Risk of contamination from dual-purpose use • Difficult to seal for fumigation • Vermin control may be difficult • Limited insect control options without sealing • Difficult to unload

Growers should pressure-test sealable silos once a year to check for damaged seals on openings. Storages must be able to be sealed properly to ensure high phosphine gas concentrations are held long enough to give an effective fumigation.

At an industry level, it is in growers' best interests to only fumigate in gas-tight sealable storages to help stem the rise of insect resistance to phosphine. This resistance has come about because of the prevalence of storages that are poorly sealed or unsealed during fumigation. [4]

The Kondinin Group National Agricultural Survey 2009 revealed that 85% of respondents had used phosphine at least once during the previous 5 years, and of those users, 37% used phosphine every year for the past 5 years. A GRDC survey during 2010 revealed that only 36% of growers using phosphine applied it correctly—in a gas-tight, sealable silo.

Research shows that fumigating in a storage that is not gas-tight does not achieve a sufficient concentration of fumigant for long enough to kill pests at all life-cycle stages. For effective phosphine fumigation, a minimum gas concentration of 300 parts per million (ppm) for 7 days or 200 ppm for 10 days is required. (Figure 1). Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks. (Figure 2). The rest of the silo also suffers from reduced gas levels. [5]

4 C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide. GRDC Stored Grain Project, January 2011 (reprinted June 2013).

5 P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. GRDC Grain Storage Fact Sheet, September 2010.

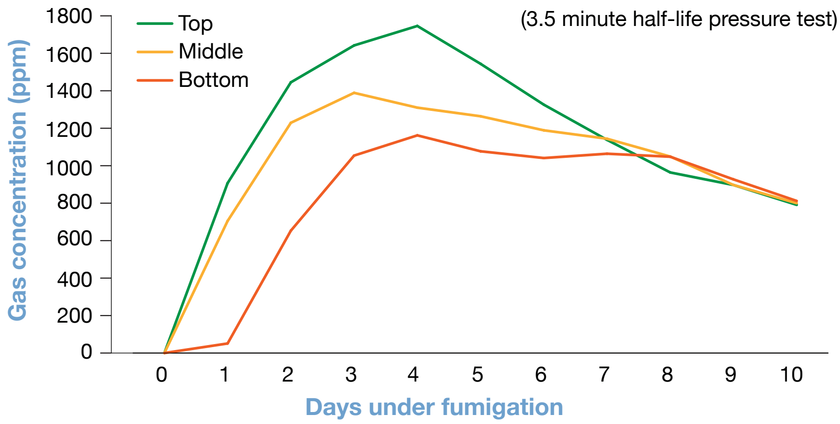


Figure 2: Gas concentration in gas-tight silo. (Source: QDAFF)

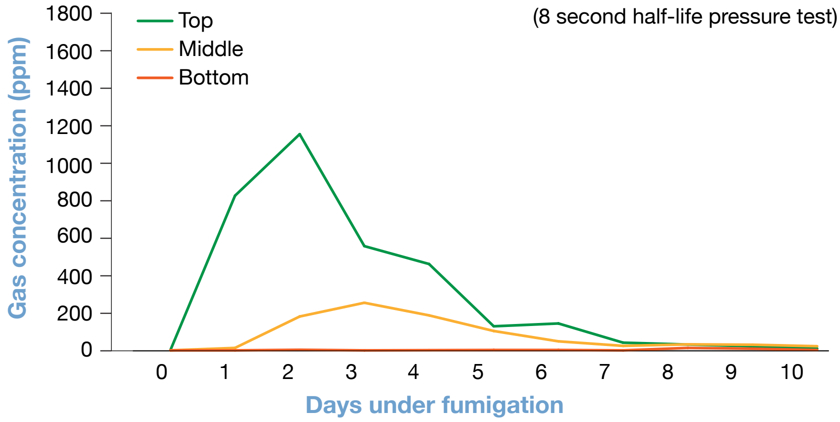


Figure 3: Gas concentration in a non-gas-tight silo. (Source: QDAFF)

To find out more about how to pressure-test silos, visit 'Fumigating with phosphine, other fumigants and controlled atmospheres' at: http://www.grdc.com.au/~/media/FC440FBD7AE14140A08DAA3F2962E501.pdf

Aeration of stored oats is the key non-chemical tool used to minimise the risk of insect infestations and spoiling through heat and/or moisture damage.

Aeration controllers that automatically monitor air temperature and humidity are designed to turn fans on and off at the optimum times. The controller reduces the risk of having fans running on storages at times that may potentially cause grain damage. Most aeration controllers have hour meters fitted, so run-times can be checked to ensure they are within range of the expected total average hours per month, for example, 100 hrs/month.

It is important to separate aeration systems commonly used for "aeration cooling" and aeration systems designed specifically to achieve reliable "aeration drying". Serious grain damage has occurred when fan performance has not met the required airflow rates as measured in litres per second per tonne (L/s.t). If aeration drying of grain is attempted with elevated moisture levels using an inadequate airflow rate and/or a poor system design, sections of the storage can develop very high moisture and grain temperatures. With low airflow rates moisture drying fronts move too slowly to prevent grain spoilage. Grain-quality losses from moulds and heat occur rapidly. This type of damage often makes the grain difficult to sell and may cause physical damage to the silo itself. [6]

Researchers in Australia have developed a device that measures working airflow rates of fans fitted to grain storage. Called the 'A-Flow', it has been validated under controlled

6 P Burrill, A Ridley (2012) Performance testing aeration systems. GRDC Research Update Northern Region, Spring

conditions, using an Australian Standard fan-performance test rig, to be within 2.6% of the true fan output. The device was used on a typical grain storage that was in the process of aerating recently harvested grain. A fan advertised to provide 1000 L/s (equivalent to 6.7L/s.t on a full 150-t silo) was tested and shown to be producing only 1.8 L/s.t. Because of this test, the farmer recognised a need to make changes to his current aeration system design.

A number of changes may be required if airflow rates are not suitable for efficient aeration cooling or drying. A new fan that is better suited to the task could be installed, or the amount of grain in the silo reduced to increase flow rate per tonne of grain.

Detailed information about selecting, siting and fitting-out silos, grain storage bags, sheds and bunkers is contained in the GRDC Grains Industry Guide 'Grain storage facilities: Planning for efficiency and quality'.

13.2 Hygiene

Effective grain hygiene and aeration cooling can overcome 75% of pest problems in stored grain. All grain residues should be cleaned out when silos and grain-handling equipment are not in use to help minimise the establishment and build-up of pest populations.

In one year, a bag of infested grain can produce more than one million insects, which can walk and fly to other grain storages where they will start new infestations. Meticulous grain hygiene involves removing any grain residues that can harbour pests and allow them to breed. Grain pests live in protected, sheltered areas in grain handling equipment and storage and breed best in warm conditions. Insects will also breed in outside dumps of unwanted grain. Try to bury grain or spread out unwanted grain to a shallow depth of less than 20 mm so insects are exposed to the daily temperature extremes and other insect predators.

Figure 4: Poor grain hygiene undermines effective stored grain insect control. (Photo: QDAFF)

A trial in Queensland revealed more than 1000 lesser grain borers (*Rhyzopertha dominica*) (Figure 5) in the first 40 L of grain through a harvester at the start of harvest; this harvester was considered reasonably clean at the end of the previous season. [7] Further studies in Queensland revealed that insects are least mobile during the colder winter months of the year. Cleaning around silos in the winter months before spring, this can reduce insect numbers before they become mobile.

Figure 5: Ryzopertha dominica. (Photo: QDAFF)

Successful grain hygiene involves cleaning all areas where grain residues become trapped in storages and equipment. Grain pests can survive in a tiny amount of grain, which can go on to infest freshly harvested clean grain. Harvesters and grain-handling equipment should be cleaned out thoroughly with compressed air after use.

After grain storages and handling equipment are cleaned, they should be treated with a structural treatment. Diatomaceous earth (DE) is an amorphous silica also commonly known as the commercial product 'Dryacide'™ and is widely used for this purpose. It acts by absorbing the insect's cuticle or protective waxy exterior, causing death by desiccation. If applied correctly with good coverage in a dry environment, DE can provide up to 12 months' protection by killing most species of grain insects and with no known risk of resistance. It can be applied as a dry dust or slurry spray.

While many cereal grains buyers accept approved chemical insecticide structural treatments to storages, growers should avoid using them, or wash the storage out, before storing oilseeds and pulses. As there are now a number of export and domestic markets that require "pesticide residue free" grain (PRF), growers are advised to check with potential grain buyers before using grain protectants or structural treatments.

To find out more about what to use and when and how to clean equipment and storages to minimise the chance of insect infestation, visit www.grdc.com.au/GRDC-FS-HygieneStructuralTreatments to download the GRDC's Grain Storage Fact Sheet 'Hygiene and structural treatment for grain storages' (June 2013).

[7] P Burrill, P Botta, C Newman, B White, C Warrick (2013) Northern and southern regions—Grain storage pest control guide. GRDC Grain Storage Fact Sheet, June 2013.

More information

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf page 121

13.3 Grain protectants and fumigants

Grain Trade Australia is aware of cases where various chemicals have been used to treat stored grain that are not approved for grain or that particular grain type. When they are detected, an entire shipload can be rejected, often with serious long-term consequences for important Australian grain markets.

Markets that require PRF ('pesticide residue free') grain, do not rule out the use of some fumigants, including phosphine. However, PRF grain should not have any chemical residues from treatments that are applied directly to the grain as grain protectants. Before using a grain protectant or fumigant, growers need to check with prospective buyers, as the use of some chemicals may exclude grain from certain markets.

Although phosphine has resistance issues, it is widely accepted as having no residue issues. The 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. The break is provided by moving the grain to eliminate pockets where the fumigant may fail to penetrate, and by retreating it with an alternative disinfestant or protectant. [8]

Figure 6: Phosphine is widely accepted as having no residue issues. (Photo: QDAFF)

Recent research has identified the genes responsible for insect resistance to phosphine. A genetic analysis of insect samples collected from south-eastern Queensland between 2006 and 2011 has allowed researchers to confirm the increasing incidence of phosphine resistance in the region. Whereas few resistance markers were found in insects collected in 2006, by 2011 most collections had insects that carried the resistance gene. Further testing with DNA markers that can detect phosphine resistance is expected to identify problem insects before resistance becomes entrenched, and thereby help to prolong phosphine's effective life, as well as increasing the usefulness of the break strategy. [9]

8 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry. Cooperative Research Centre for National Plant Biosecurity Technical Report.

9 D Schlipalius (2013) Genetic clue to thwart phosphine resistance. GRDC Ground Cover, Issue 102, Jan.–Feb. 2013.

Table 2: Resistance and efficacy guide for stored grain insects (northern and southern regions) in cereal grains

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®)[3]	1							
Dichlorvos (e.g. Dichlorvos 1140®)[10]	7–28							9
Grain protectants—applied postharvest. Poor adult control if applied to infested grain								
Pirimiphos-methyl (Actellic 900®)	nil[2]							
Fenitrothion (Fenitrothion 1000®)[4]	1–90							
Chlorpyrifos-methyl (Reldan Grain Protector®)[5]	Nil[2]							
Methoprene (Grain Star 50®)	Nil[6]		7		7			
'Combined products' (Reldan Plus IGR Grain Protector)	Nil[2]							
Deltamethrin (K-Obiol®)[10]	Nil[2]							
Diatomaceous earth, amorphous silica—effective internal structural treatment for storages and equipment. Specific-use grain treatments								
Diatomaceous earth, amorphous silica (Dryacide®)[8]	Nil[2]							

Not registered for this pest
High-level resistance in flat grain beetle has been identified, send insects for testing if fumigation failures occur
Resistant species likely to survive this structural treatment for storage and equipment
Resistance widespread (unlikely to be effective)
Effective control

1 Unlikely to be effective in unsealed sites, causing resistance, see label for definitions
2 When used as directed on label
3 Total of (exposure + ventilation + withholding) = 10 to 27 days
4 Nufarm label only
5 Stored grains except malting barley and rice/ stored lupins registration for Victoria only/ not on stored maize destined for export
6 When applied as directed, do not move treated grain for 24 hours
7 Periods of 6–9 months storage including mixture in adulticide (e.g. Fenitrothion at label rate)
8 Do not use on stored maize destined for export, or on grain delivered to bulk-handling authorities
9 Dichlorvos 500g/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

According to research results from scientists at Queensland's Department of Agriculture, Fisheries and Forestry (QDAFF), sulfuryl fluoride (SF) has excellent potential as an alternative fumigant to control phosphine-resistant grain storage pests (Table 2). It is currently registered in Australia as a grain disinfestant. Supplied under the trade name 'ProFume', SF can only be used by a licenced fumigator.

Field trials have shown that SF can control strong phosphine-resistant populations of rusty grain beetle (*Cryptolestes ferrugineus*). Monthly sampling of fumigated grain has revealed no live insects for three consecutive months in large-scale bunker (pad) storages after the fumigation.

Annual resistance-monitoring data was analysed to assess the impact of using SF as an alternative fumigant to phosphine. This revealed that after the introduction of SF in central storages across the northern and southern grain regions in 2010, there was a 50% reduction in the incidence of strongly phosphine-resistant populations of rusty grain beetle at the end of the first year, and the downward trend is continuing. Complimentary laboratory experiments have shown that phosphine resistance does not show cross-resistance to SF, which is an additional advantage of using SF. [10]

Effective phosphine fumigation can be achieved by placing the chemical at the rate directed on the label onto a tray and hanging it in the top of a pressure-tested, sealable silo. A ground-level application system is also an efficient application method and these can be combined with a silo recirculation system on larger silos to improve the speed of gas distribution. After fumigation, grain should be ventilated for a minimum of 1 day with aeration fans running, or 5 days if no fans are fitted. A minimum withholding period of 2 days is required after ventilation before grain can be used for human consumption or stock-feed. The total time required for fumigating ranges from 7 to 20 days depending on grain temperature and the storage structure.

To find out more, visit 'Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide': http://www.grdc.com.au/~/media/FC440FBD7AE14140A08DAA3F2962E501.pdf

Two new grain protectants have recently become available. These include:

- K-Obiol (active ingredients deltamethrin 50 g/L, piperonyl butoxide 400 g/L): Features acceptable efficacy against the common storage pest lesser grain borer, which has developed widespread resistance to current insecticides. Insect resistance surveys in the past consistently detected low levels of deltamethrin-resistant insect strains in the industry. This is a warning that resistant populations could increase quickly with widespread excessive use of one product. A 'product stewardship' program has been developed to ensure correct use of the product. [11]
- Conserve On-Farm: Has three active ingredients (chlorpyrifos-methyl 550 g/L, S-methoprene 30 g/L, spinosad 120 g/L) to control most major insect pests of stored grain, including the resistant lesser grain borer. The MRLs have been established with key trading partners and there are no issues with meat residue bioaccumulation.

A grain disinfestant combined with carbon dioxide gas, currently has some limitations.

- VAPORMATE (active ingredient ethyl formate 166.7 g/kg): Approved for use in stored cereals and oilseeds. It is registered to control all life-stages of the major storage pest insects: lesser grain borer, rust-red flour beetle (*Tribolium* spp.), sawtoothed beetle, flat grain beetles, storage moths and psocids (booklice). However it does not fully control all stages of rice weevil. It must only be used by a licenced fumigator.

Controlled atmosphere/non-chemical treatment options include:

- Carbon dioxide (CO_2): Involves displacing the oxygen inside a gas-tight silo with a high concentration of CO_2 combined with a low oxygen atmosphere lethal to grain pests. To achieve a complete kill of all grain pests at all life-stages, CO_2 must be maintained at a minimum concentration of 35% for 15 days.
- Nitrogen (N_2): Provides insect control and quality preservation without chemicals. It is safe to use and environmentally acceptable, and the main operating cost is electricity used by the equipment to produce nitrogen gas. The process uses pressure swing adsorption (PSA) technology to produce N_2, thereby modifying the atmosphere within the grain storage to create a very high concentration of N_2, and

[10] M Nayak (2012) Sulfuryl fluoride—A solution to phosphine resistance? GRDC Research Update Northern Region, Spring 2012, Issue 66.

[11] P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014. GRDC Update, July 2013.

starving insect pests of oxygen. [12]There are no residues, so grains can be traded at any time.

Silo bags as well as silos can be fumigated. Research conducted by Andrew Ridley and Philip Burrill from DAFF Queensland and Queensland farmer Chris Cook found that sufficient concentrations of phosphine can be maintained for the required time to successfully fumigate grain in a silo bag. Trials on a typical, 75 m long bag containing approximately 230 t of grain successfully controlled all life stages of the lesser grain borer.

Figure 7: Silo bags can also be fumigated. (Photo: QDAFF)

When using phosphine in silos or silo bags it is illegal to mix phosphine tablets directly with grain due to tablet residue issues. As trays in silo bags are not practical, tablets are placed in perforated conduit to contain tablets and spent dust. The 1 m tubes are speared horizontally into the silo bag and removed at the end of the fumigation. Trial results suggest that the spears should be no more than 7 m apart and fumigation should occur over 12–14 days (Figure 8). In previous trials when spears were spaced 12 m apart, the phosphine gas took too long to diffused throughout the whole bag. [13]

[12] C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide. GRDC Stored Grain Project, January 2011 (reprinted June 2013).

[13] P Burrill, A Ridley (2012) Silo bag fumigation. GRDC Research Update Northern Region, Spring 2012, Issue 66.

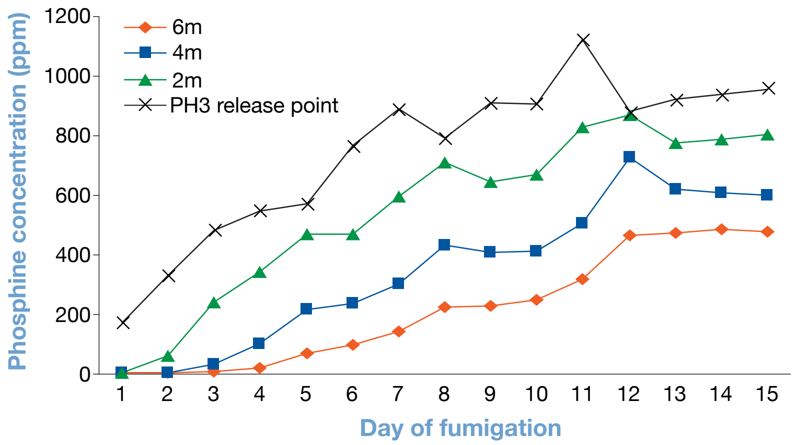


Figure 8: Spread of phosphine gas in a silo bag from a release point to gas monitoring lines at 2, 4 and 6 m along a silo bag.

13.4 Aeration during storage

Aeration has a vital role in both maintaining grain quality attributes and reducing insect pest problems in storage. Most grain in storage is best held under aeration cooling management with the silo having appropriate roof venting. As a general rule, silos should only be sealed up during a fumigation operation which typically lasts for one or two weeks.

Aeration typically reduces stored grain temperatures by more than 10°C during summer which significantly reduces the threat of a serious insect infestation. Producers in the Darling Downs and northern New South Wales regions should achieve grain temperatures in storage of 20–23°C during summer storage and less than 15°C in winter. [14]

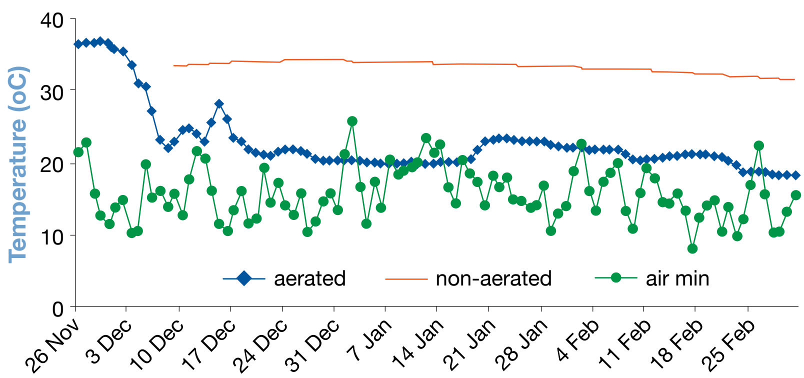


Figure 9: Comparison of wheat grain temperatures in aerated and non-aerated silos.

As soon as grain is harvested and put in storage, run the aeration system 24 hours per day for the first 5 days to reduce grain temperatures and produce uniform moisture conditions in the grain bulk. Without aeration, grain holds its heat as it is an effective insulator and will maintain its warm harvest temperature for a long time (Figure 9). Cereals at typical harvest temperatures of 28–35°C and moisture content greater than 13–14% provide ideal conditions for mould and insect growth (Table 3). [15]

[14] P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014. GRDC Update, July 2013.

[15] P Burrill, P Botta, C Newman, B White, C Warrick (2013) Dealing with high-moisture grain. GRDC Grain Storage Fact Sheet, June 2013.

Table 3: The effect of grain temperature on insects and mould. (Source: Kondinin Group)

Grain temperature (ºC)	Insect and mould development	Grain moisture content (%)
40–55	Seed damage occurs, reducing viability	
30–40	Mould and insects are prolific	>18
25–30	Mould and insects active	13–18
20–25	Mould development is limited	10–13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Although adult insects can still survive at low temperatures, most storage pest's life cycle stages are very slow or stopped at temperatures below 18–20°C. One of the more cold tolerate pests, the common rice weevil, does not increase its population with grain temperatures below 15°C. Insect pest lifecycles (egg, larvae, pupae and adult) are lengthened from the typical 4 weeks at warm temperatures (30–35°C) to 12–17 weeks at cooler temperatures (20–23°C).

A national upper limit for moisture of 12.5% applies to oats at receival, but deliveries are usually in the range 10.5–11%. Special measures must be taken to minimise the risk of insect infestations or heat damage if the grain is harvested in damp conditions. Research also shows that cereals stored at a higher moisture content will have a reduced germination percentage and seedling vigour.

NSW Department of Primary Industries trials have shown that grain temperature should be kept below 15°C to protect seed quality and stop all major insect infestations, and aeration slows the rate of deterioration of seed if the moisture content is kept at 12.5–14%. [16]

A trial by DAFF Queensland revealed that high-moisture grain generates heat when put into a confined storage, such as a silo. Oats with 16.5% moisture content at a temperature of 28°C was put into a silo with no aeration. Within hours, the grain temperature reached 39°C and within 2 days reached 46°C, providing ideal conditions for mould growth and grain damage (Figure 10). [17]

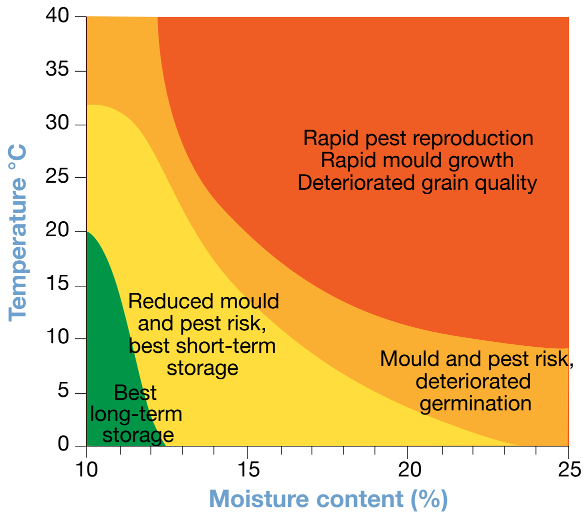


Figure 10: Effects of temperature and moisture on stored grain.

(Source: CSIRO Ecosystems sciences as published in http://www.grdc.com.au/~/media/36D51B725EF44EC892BCD3C0A9F4602C.pdf)

[16] NSW Department of Primary Industries 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

[17] P Burrill, P Botta, C Newman, B White, C Warrick (2013) Dealing with high-moisture grain. GRDC Grain Storage Fact Sheet, June 2013.

If use of a grain dryer is not an option, grain that is over the standard safe storage moisture content of 12% and up to the moderate moisture level of 15% can be managed by aerating until drying equipment is available. Blending with low-moisture grain and aerating is also a commonly used strategy (Figure 6).

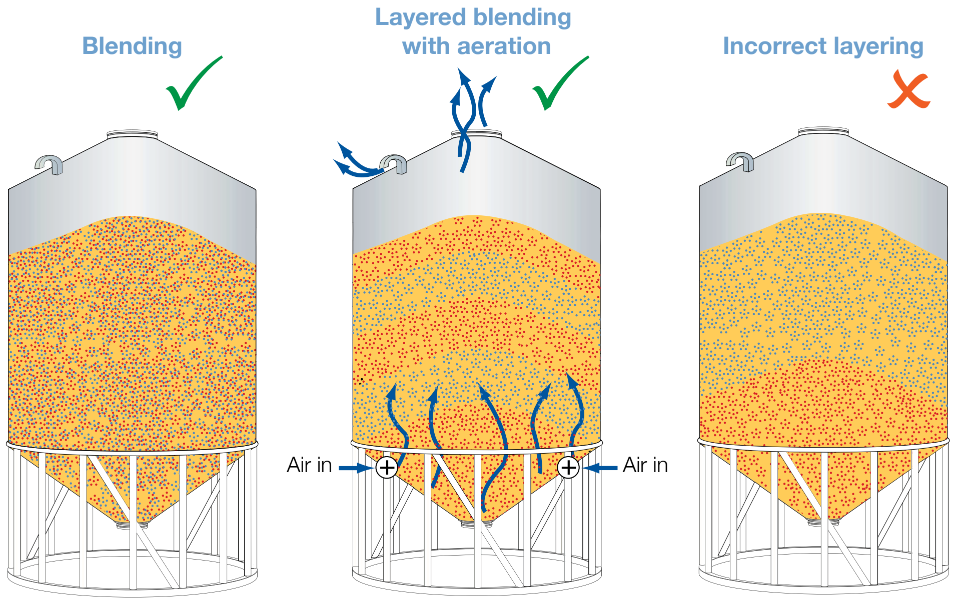


Figure 11: Correct blending. (Source: Kondinin Group)

Aeration drying forces large volumes of air through the grain in storage and slowly removes moisture. Supplementary heating can be added when ambient conditions typically have high humidity. Aeration drying can be done in a purpose-built drying silo or a partly filled silo with high-capacity aeration fans.

Dedicated driers can be used to dry oats in batches or with continuous-flow, before it is put into silos, but excessive heat applied post-harvest can reduce the quality of milling oats.

A wet harvest or damp conditions can make drying prior to storage a necessity. These rules will help you to decide whether it is safe to store your oats without drying:

- Oats that does not exceed the maximum moisture level of 12.5% can be aeration cooled without drying to slow insect development and maintain quality during storage.
- Grain of up to 15% moisture can be safely held under continuous aeration for a number of weeks until a hot air drier or an aeration drying process can take place to reduce the moisture for safe longer term storage. Blending with dry grain and aerating may also be feasible.
- Grain of more than 15% moisture should be dried to a safe storage moisture immediately, then held under normal aeration cooling for maintenance.

13.5 Monitoring oats

Growers are advised to monitor all grain in storage at least monthly. During warm periods in summer, if grain moisture content is near the upper end of the safe storage moisture content, monitoring every two weeks is advisable. Insect pests present in the on-farm storage environment must be identified so growers can exploit the best use of both chemical and/or non-chemical control measures to control them.

Oats for domestic or export use must not contain live storage pests, and feed grades can lose nutritional value and palatability through infestations. Keeping storage pests out of planting seed grain is also important because they can reduce the germination and vigour quality of seed with serious consequences for the next oats crop.

When monitoring stored grain through sieving, trapping and quality inspections, growers should keep records of findings. If possible, grain temperature should also be checked regularly. Any grain treatments applied need to be recorded. [18]

Figure 12: Keep records of findings from stored grain insect monitoring. (Photo: QDAFF)

The lesser grain borer and rust-red flour beetle are some of the most common insect pest found in stored cereals. Other common species to watch for include weevils (*Sitophilus* spp.), saw-toothed grain beetle (*Oryzaephilus* spp.), flat grain beetles and rusty grain beetle (*Cryptolestes* spp.), psocids (booklice), Indian meal moth (*Plodia interpunctella*) and Angoumois grain moth (*Sitotroga cerealella*). Another dozen or so beetles, and mites are sometimes present as pests in stored cereal grain.

Photographs and descriptions of these pests can be found in the GRDC Grain Storage Fact Sheet entitled 'Northern and southern regions stored grain pests—Identification'. Or, GRDC "Stored grain pest identification – The Back Pocket Guide". Download it from: http://storedgrain.com.au/northern-southern-regions-grain-storage-pest-control-guide/ or http://www.grdc.com.au/GRDC-FS-StoredGrainPestID

This Fact Sheet also outlines how to monitor stored grain for infestations. Here are some basic points to follow when monitoring for insect pests in your grain:

- Sample and sieve grain from the top and bottom of grain storages every month (4 weeks) for early pest detection. Pitfall traps installed in the top of the grain store will also help early detection of storage pests.
- Holding an insect sieve in the sunlight will encourage insect movement, making pests easier to see. Sieve samples on to a white tray, again to make small insects easier to see. Sieves should have 2 mm mesh and need to hold at least 1 L of grain.
- To help identify live grain pests, place them into a clean glass container. Briefly warm the jar in the sun to encourage insect activity. Weevils and saw-toothed grain beetles can walk up the walls of the glass easily, but flour beetles and lesser grain borer cannot. Look closely at the insects walking up the glass—weevils have a curved snout at the front and saw-toothed grain beetles do not. [19]

[18] P Burrill, P Botta, C Newman (2010) Aeration cooling for pest control. GRDC Grain Storage Fact Sheet, September 2010.

[19] P Burrill, P Botta, C Newman, B White, C Warrick (2013) Northern and southern regions stored grain pests—Identification. Grain Storage Fact Sheet, June 2013.

Recent research in southern and central Queensland has shown that industry may need to consider an area-wide approach to pest and resistance management. The research indicates flight dispersal by the lesser grain borer and the rust-red flour beetle, both of which are major insect pests of stored grain. The research involved setting beetle traps along a 30 km transect in the Emerald district and showed that the lesser grain borer flies all year round in Central Queensland, whereas the flour beetle appeared to be located mainly around storages during the winter months, spreading into the surrounding district in summer. This study highlights the importance of finding and dealing with infestations to limit the number of pests that can infest clean grain. In another study, beetles were found to be flying between farms on a scale of at least 100 km. [20]

NOTE: Exotic pests including Karnal bunt (*Tilletia indica*) and Khapra beetle (*Trogoderma granarium*) are a threat to the Australian grains industry—report sightings immediately.

More information

[NSW DPI (2015) Winter crop variety sowing guide 2005]

[20] G Daglish, A Ridley (2012) Stored grain insects: How they spread and implications for resistance. GRDC Research Update Northern Region, Spring 2012, Issue 66.

SECTION 14

Environmental issues

More information

R Malik, B Paynter, C Parsons and A McLarty (2015) Growing oats in Western Australia for hay and grain, ResearchGate Bulletin 4798, DAFWA,

http://www.grdc.com.au/GRDC-FS-FrostRisk

14.1 Frost issues for oats

Frost occurs on clear nights in early spring when the air temperature drops to 2°C or lower. Damage to crops from frost may occur at any stage of development but is most damaging at and around flowering. Symptoms of frost damage can occur as sterility and stem damage. Physical damage to the plant occurs when ice forms inside the plant tissue, as expanding ice bursts membranes, resulting in mechanical damage and dehydration injury. Frost damage can reduce both grain yield and quality. [1]

The real cost of frost is a combination of the actual cost, due to both reduced yield and quality, and the hidden cost of management tactics used to try to minimise frost risk.

The hidden costs associated with conservative management to minimise frost risk include:

- delayed sowing and its associated yield reduction
- sowing less profitable crops such as barley and oats
- avoiding cropping on the valley floors, which also contain some of the most productive parts of the landscape.

Frost does not have any direct off-site impact on resource, biosecurity, economy or industry.

Frost can have quite a large social impact as it happens so suddenly, unlike drought, which growers can adapt to mentally and financially by reducing further inputs as it unfolds. [2]

14.1.1 Frost tolerance of crops

Growers can lower frost risk in paddocks that frequently experience frost by growing either frost-tolerant crops or growing more pastures. If a grower wishes to sow a crop in a high-risk paddock, either for rotational or price reasons, they can choose a more frost-tolerant crop, or a crop that has alternative uses such as oats for hay as this will help reduce losses from frost damage. [3]

Frost-tolerant crops

Oats is regarded as the cereal crop least susceptible to frost damage, followed by cereal rye, barley, wheat and triticale (Table 1). Oats is thought to be about 4°C more tolerant than wheat, while barley is thought to be about 2°C more tolerant. [4]

1 DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

2 DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

3 DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

4 DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

Table 1: Order of frost tolerance of cereal crops

Crop in order of tolerance (highest to lowest)	Notes
Oats	About 4°C more tolerant than wheat
Cereal rye	
Barley	About 2°C more tolerant than wheat
Wheat	
Triticale	

Canola is quite susceptible to frost and least tolerant to frost damage from flowering to the clear watery stage (about 60% moisture).

Field peas are the most frost-susceptible pulse crop, followed by faba beans and lupins.

14.1.2 Growing oaten hay on frost-prone paddocks

Growing oaten hay on frost-prone paddocks minimises the frost risk as it is cut soon after flowering, avoiding the frost-sensitive period. If severe frost damage does occur to other crops, baling them for hay may reduce economic loss. Oats are much more tolerant than other cereals to frost events that occur during vegetative growth and flowering. [5]

Figure 1: Growing hay on frost-prone paddocks can benefit farming systems and whole farm profitability. (Photo: DAFWA)

Costs:

- Growing hay is a capital-intensive enterprise.
- Hay is a high-risk enterprise as time of cutting and baling is critical for maintaining hay quality.

More information

DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

DAFWA (2000) Cereals: frost identification guide, Bulletin 4375, https://www.grdc.com.au/~/media/922066B41721409E9EFC6014A333769B.pdf

DAFWA (2016) Growing oaten hay on frost-prone paddocks, https://www.agric.wa.gov.au/frost/growing-oaten-hay-frost-prone-paddocks

5 DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

- Late spring rains, which benefit grain crops, can be detrimental to hay quality and ultimately returns.
- Transport can be expensive, depending on your location.
- The price of hay is highly volatile and depends on supply and quality each season.
- Hay removes large quantities of nutrients, particularly potassium, that need to be replenished for the following crop, increasing input costs. Hay crops remove greater amounts of potassium (about 10 kg/t) than other cereals harvested for grain. [6]

Benefits:

- Oats are generally more frost tolerant than wheat and barley so the likelihood of frost damage is reduced.
- Farm enterprises (and risk) become more diversified.
- Frost-prone paddocks usually have highly productive soils in frost-free seasons and growing hay capitalises on the production potential while minimising frost risk.
- Oaten hay provides a break crop to manage weeds.
- High quality hay is now sort after by the export markets. [7 8 9 10]

14.2 Waterlogging

Waterlogging is not uncommon in the heavy vertisol clays that are common throughout the northern part of the northern region.

Where does it occur?

Waterlogging occurs when there is insufficient oxygen in the soil pore space for plant roots to adequately respire.

Root-harming gases such as carbon dioxide and ethylene also accumulate in the root zone and affect the plants.

A number of situations increase the damage caused by waterlogging damage.

14.2.1 Waterlogging symptoms

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.

Seminal roots are important for accessing deep subsoil moisture. If damaged by waterlogging the plants may be more sensitive to spring drought.

6 DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

7 DAFWA (2016) Frost and cropping, https://www.agric.wa.gov.au/frost/frost-and-cropping

8 R Malik, C Parsons, A McLarty (2010) Growing oats in Western Australia for hay and grain. Bulletin 4798. Department of Agriculture and Food, Western Australia.

9 M Rebbeck, G Knell (2009) Early season planning to minimise frost risk, Ground Cover Issue 79, March–April 2009. Grains Research and Development Corporation, Canberra.

10 MA Rebbeck, G Knell G (2007) 'Managing frost risk: a guide for southern Australian grains', D Reuter (ed) Grains Research and Development Corporation, South Australian Research and Development Institute, Adelaide.

Management strategies

When sowing a crop in a potentially waterlogging soil consider:

- Sowing the paddock early so the crop is established before the wet, cold winter conditions set in. Once waterlogged paddocks get wet in the winter months, accessing them for sowing can be an issue.
- Delay sowing if a significant rainfall event is forecast.
- If sowing has to occur, plant the seed shallow.
- Use recommended seed treatments as waterlogged plants will be slow to grow and hence are more subject to diseases.
- Ensure adequate crop nutrition. A healthy plant will be better equipped to grow away from a stressed situation.

Management strategies are limited once the crop has emerged. Paddocks that have good soil structure (i.e. little to no compaction) will be freer draining than those with compromised soils and the duration and severity of the waterlogging will be less. [11]

14.2.2 Diagnosing waterlogging and salinity in oats

Oats are very tolerant of waterlogging but are more susceptible to salinity damage than wheat and barley.

Salinity affects growth by reducing plant root ability to extract water from the soil, and chloride toxicity.

Primary salinity occurs naturally in heavy-textured, high-alkaline and usually well-drained soils with high levels of salt in the subsoil.

Secondary salinity has been caused by salt accumulation from saline water tables or seepages that have increased after land clearing.

Salinity is frequently accompanied by waterlogging in autumn and winter, which greatly increases plant damage.

What to look for

Paddock

Poor germination or pale plants, in water collecting areas, particularly on shallow duplex soils.

Wet soil and/or water-loving weeds or salt-tolerant plants only as salinity increases.

Nitrogen-deficient plants with more leaf necrosis and premature death in more saline areas (Figure 2).

Plant: salinity symptoms

Plants have a harsh droughted appearance, and may be smaller with smaller dull leaves (Figure 3).

Old leaves develop dull yellow tips and die back from the tips and edge (Figure 4).

Premature death (Figure 5).

What else could it be?

Condition	Similarities	Differences
Diagnosing nitrogen deficiency in oats	Similar foliar symptoms	No root browning and less old leaf necrosis and symptoms are not confined to wet or saline areas.

Low-nitrogen-status crops

[11] DAFWA (2015) Diagnosing waterlogging and salinity in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-and-salinity-oats

Management strategies

Avoid sowing on saline areas.

Sow as early as possible with a higher seeding rate if there is a waterlogging risk.

On waterlogged sites treating crops with liquid UAN is a quicker and more efficient way to help the plants recover than using urea. This is due to a small amount of leaf uptake of nitrogen and that 50% of the nitrogen is in the nitrate form ready for root uptake.

Drainage may be appropriate on sandy duplex soils on sloping sites.

How can it 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. [12]

Figure 2: Nitrogen deficiency symptoms. (Photo: DAFWA)

Figure 3: Old leaf discolouration and brown seminal root from high salinity levels. (Photo: DAFWA)

[12] DAFWA (2015) Diagnosing waterlogging and salinity in oats, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-and-salinity-oats

Figure 4: Old leaf browning, necrosis from waterlogging and mild salinity. (Photo: DAFWA)

Figure 5: Water-stressed plant in saline patch. (Photo: DAFWA)

SECTION 15

Marketing

The final step in generating farm income is converting the tonnes produced into dollars at the farm gate. This section provides best in class marketing guidelines for managing price variability to protect income and cash-flow.

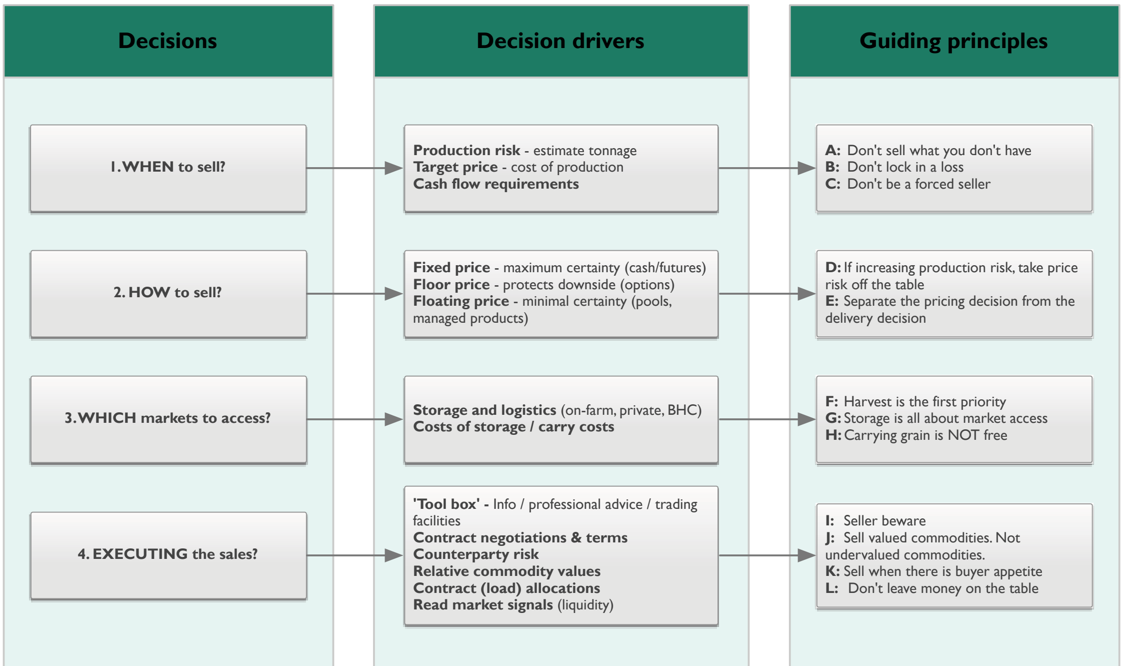
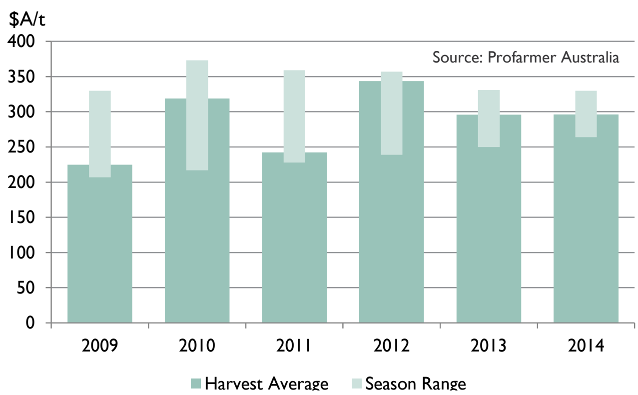


Figure 1: Grain selling flow chart.

Figure 1 shows a grain selling flow chart that summarises:

- The decisions to be made
- The drivers behind the decisions
- The guiding principles for each decision point



Note to figure:
Kwinana APW2 wheat prices have varied A$60-$160/t over the past 6 years (25-60% variability). For a property producing 2,000 tonne of wheat this means $120,000-$320,000 difference in income depending on price management skill.

Figure 2: Selling principles

15.1 Selling Principles

The aim of a selling program is to achieve a profitable average price (the target price) across the entire business. This requires managing several unknowns to establish the target price and then working towards achieving that target price.

Unknowns 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 growers have developed to manage production unknowns can be used to manage pricing unknowns. This guide will help growers manage and overcome price uncertainty.

15.1.1 Be prepared

Being prepared and having a selling plan is essential for managing uncertainty. The steps involved are forming a selling strategy and a plan for effective execution of sales.

A selling strategy consists of when and how to sell.

When to sell

This requires an understanding of the farm's internal business factors including:

- production risk
- a target price based on cost of production and a desired profit margin
- business cash flow requirements

How to sell?

This is more dependent on external market factors including:

- time of year determines the pricing method
- market access determines where to sell
- relative value determines what to sell

The following diagram (Figure 3) lists key selling principles when considering sales during the growing season.

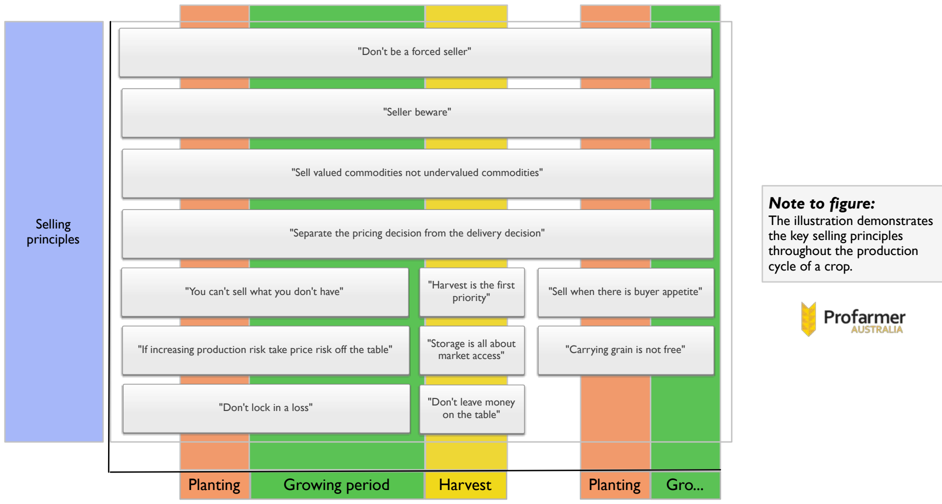


Figure 3: Grower commodity selling principles timeline.

15.1.2 Establish 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 and how to quantify those risks during the production cycle are described below.

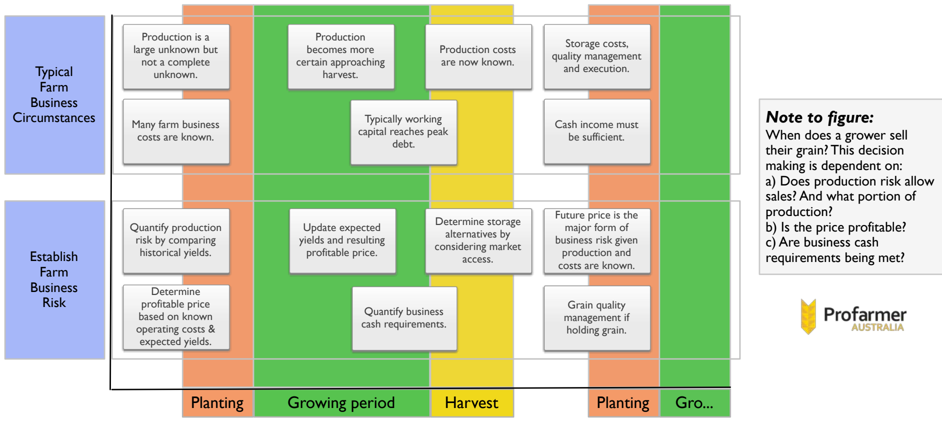


Figure 4: Typical farm business circumstances and risk.

Production risk profile of the farm

Production risk is the level of certainty around producing a crop and is influenced by location (climate and soil type), crop type, crop management, and time of the year.

Principle: "You can't sell what you don't have" – Don't increase business risk by over committing production.

Establish a production risk profile by:

1. Collating historical average yields for each crop type and a below average and above average range.
2. Assess the likelihood of achieving average based on recent seasonal conditions and seasonal outlook.
3. Revising production outlooks as the season progresses.

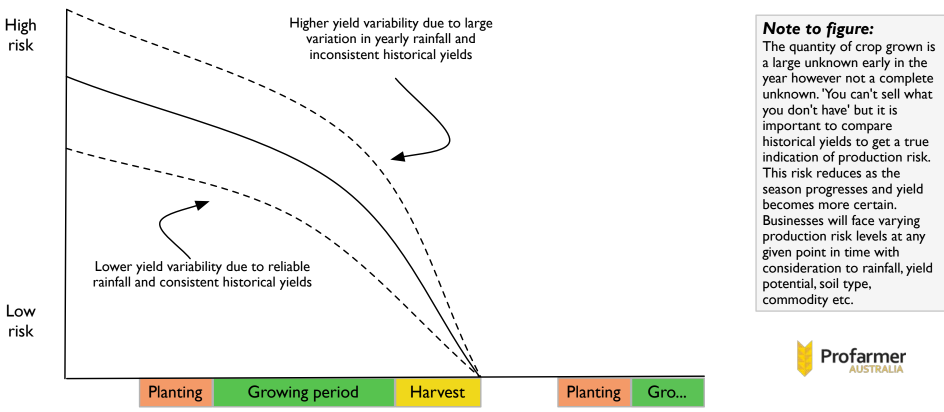


Figure 5: Typical risk profile of farm operation.

Farm costs in their entirety, variable and fixed costs (establishing a target price).

A profitable commodity target price is the cost of production per tonne plus a desired profit margin. It is essential to know the cost of production per tonne for the farm business.

Principle: "Don't lock in a loss" – If committing production ahead of harvest, ensure the price is profitable.

Steps to calculate an estimated profitable price based on total cost of production and a range of yield scenarios is provided below.

Estimating cost of production - Wheat		
Planted Area	1,200 ha	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.
Estimate Yield	2.85 t/ha	
Estimated Production	3,420 t	
Fixed costs		
Insurance and General Expenses	$100,000	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 Klause "Farming your Business") but the most important thing is that in the end all costs are accounted for.
Finance	$80,000	
Depreciation/Capital Replacement	$70,000	
Drawings	$60,000	
Other	$30,000	
Variable costs		
Seed and sowing	$48,000	Step 3: Calculate all the variable costs attributed to producing that crop. This can also be expressed as $ per ha x planted area.
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	$742,000	
Per Tonne Equivalent (Total costs + Estimated production)	$212 /t	Step 4: Add together fixed and variable costs and divide by estimated production
Per tonne costs		
Levies	$3 /t	Step 5: Add on the "per tonne" costs like levies and freight.
Cartage	$12 /t	
Freight to Port	$11 /t	
Total per tonne costs	$22 /t	Step 6: Add the "per tonne" costs to the fixed and variable per tonne costs calculated at step 4.
Cost of production Port track equiv	$259.20	
Target profit (ie 20%)	$52.00	Step 7: Add a desired profit margin to arrive at the port equivalent target profitable price.
Target price (port equiv)	**$311.20**	

Figure 6: GRDC's "Farming the Business Manual" also provides a cost of production template and tips on grain selling vs grain marketing. http://www.grdc.com.au/FarmingTheBusiness

Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables grain sales to be timed so that cash is available when required. This prevents having to sell grain below the target price to satisfy a need for cash.

Principle: "Don't be a forced seller" – Be ahead of cash requirements to avoid selling in unfavourable markets.

A typical cash-flow to grow a crop is illustrated below (Figures 7 and 8). 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. The second figure demonstrates how managing sales can change the farm's cash balance.

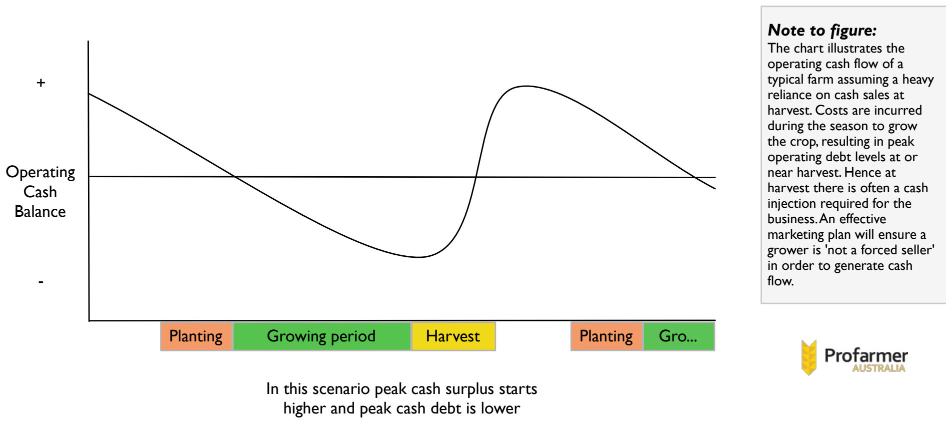


Figure 7: Typical operating cash balance.

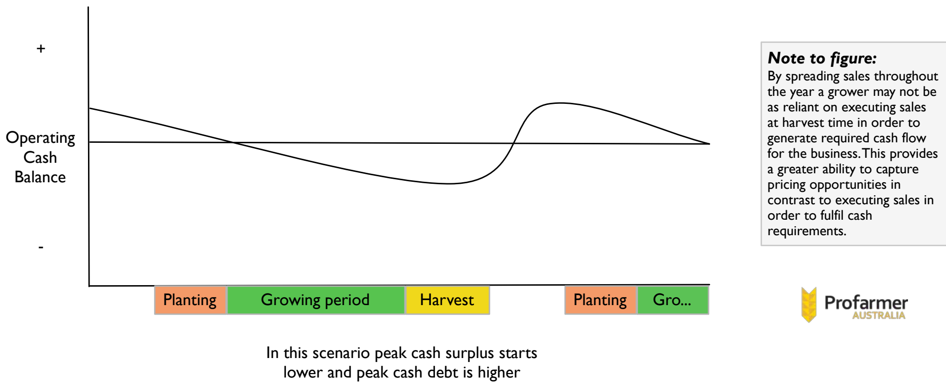


Figure 8: Typical operating cash balance.

When to sell revised

The “when to sell” steps above result in an estimated production tonnage and the risk associated with that tonnage, a target price range for each commodity, and the time of year when cash is most needed.

15.1.3 Managing your price (how to sell?)

The first part of the selling strategy answers the question “when to sell” and establishes comfort around selling a portion of the harvest.

The second part of the strategy addresses “how to sell”.

Methods of price management

Pricing products provide varying levels of price risk coverage:

Table 1: Pricing methods and how they are used for various crops

	Description	Wheat	Barley	Canola	Oats	Lupins	Field peas	Chick peas
Fixed price products	Provides the most price certainty	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash	Cash	Cash	Cash
Floor price products	Limits price downside but provides exposure to future price upside	Options on futures, floor price pools	Options on futures	Options on futures	none	none	none	none
Floating price products	Subject to both price upside and downside	Pools	Pools	Pools	Pools	Pools	Pools	Pools

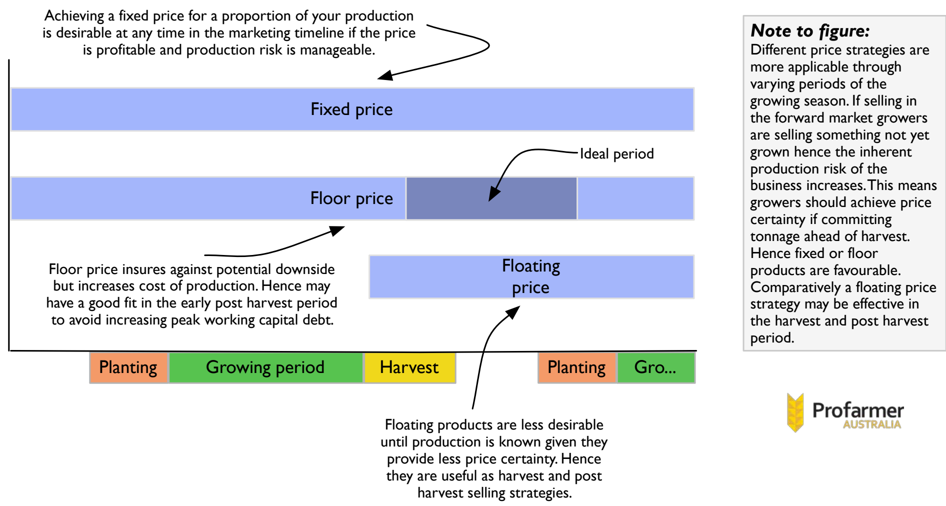


Figure 9: Summary of where different methods of price management are suited for the majority of farm businesses.

Principle: “If increasing production risk, take price risk off the table” – When committing unknown production, price certainty should be achieved to avoid increasing overall business risk.

Principle: “Separate the pricing decision from the delivery decision” – Most commodities can be sold at any time with delivery timeframes negotiable, hence price management is not determined by delivery.

Fixed price

A fixed price is achieved via cash sales and/or selling a futures position (swaps).

It provides some certainty around expected revenue from a sale as the price is largely a known except when there is a floating component in the price. For example, a multi-grade cash contract with floating spreads or a floating basis component on futures positions.

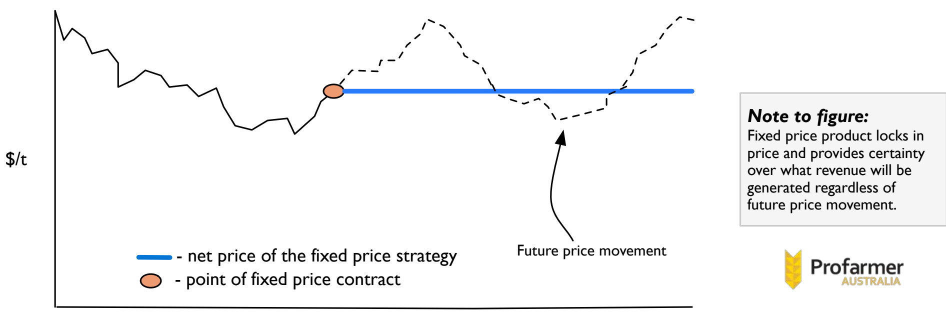


Figure 10: Fixed price strategy.

Floor price

Floor price strategies can be achieved by utilising “options” on a relevant futures exchange (if one exists), or via a managed sales program product by a third party (i.e. a pool with a defined floor price strategy). This pricing method protects against potential future downside whilst capturing any upside. The disadvantage is that the price ‘insurance’ has a cost which adds to the farm businesses’ cost of production.

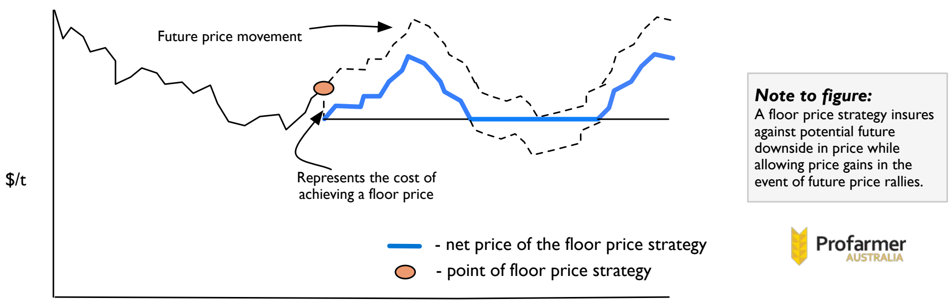


Figure 11: Floor price strategy.

Floating price

Many of the pools or managed sales programs are a floating price where the net price received will move both up and down with the future movement in price. Floating price products provide the least price certainty and are best suited for use at or after harvest rather than pre harvest.

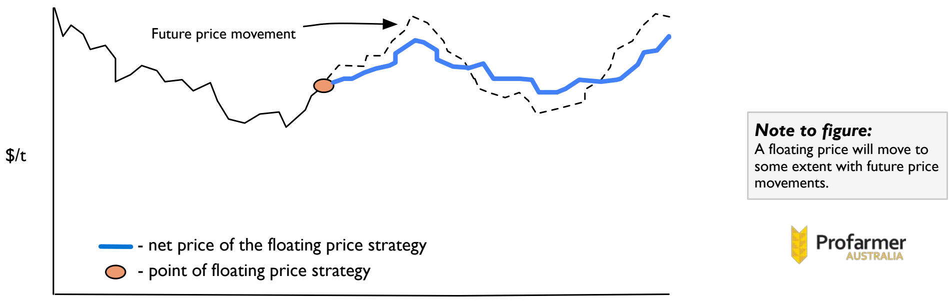


Figure 12: Floating price strategy.

How to sell revised

Fixed price strategies include physical cash sales or futures products and provide the most price certainty, but production risk must be considered.

Floor price strategies include options or floor price pools. They provide a minimum price with upside potential and rely less on production certainty but cost more.

Floating price strategies provide minimal price certainty and are best used after harvest.

15.1.4 Ensuring access to markets

Once the selling strategy of when and how to sell is sorted, planning moves to storage and delivery of commodities to ensure timely access to markets and execution of sales. At some point growers need to deliver the commodity to market. Hence planning on where to store the commodity is important in ensuring access to the market that is likely to yield the highest return.

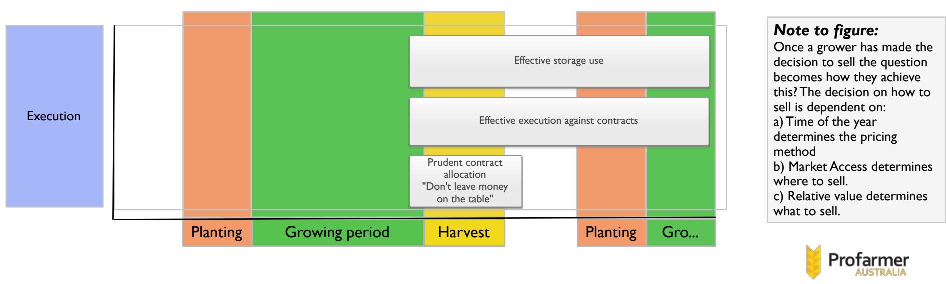


Figure 13: Effective storage decisions.

Storage and logistics

Return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access to maximise returns as well as harvest logistics.

Storage alternatives include variations around the bulk handling system, private off farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity.

Principle: “Harvest is the first priority” – Getting the crop in the bin is most critical to business success during harvest, hence selling should be planned to allow focus on harvest.

Bulk export commodities requiring significant quality management are best suited to the bulk handling system. Commodities destined for the domestic end user market (e.g. feed lot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on-farm requires prudent quality management to ensure delivery at agreed specifications and can expose the business to high risk if this aspect is not well planned. Penalties for out-of-specification grain on arrival at a buyer’s weighbridge can be expensive. The buyer has no obligation to accept delivery of an out-of-specification load. This means the grower may have to incur the cost of taking the load elsewhere whilst also potentially finding a new buyer. Hence there is potential for a distressed sale which can be costly.

On-farm storage also requires prudent delivery management to ensure commodities are received by the buyer on time with appropriate weighbridge and sampling tickets.

Principle: “Storage is all about market access” – Storage decisions depend on quality management and expected markets.

For more information on on-farm storage alternatives and economics refer to Section 14 Grain Storage.

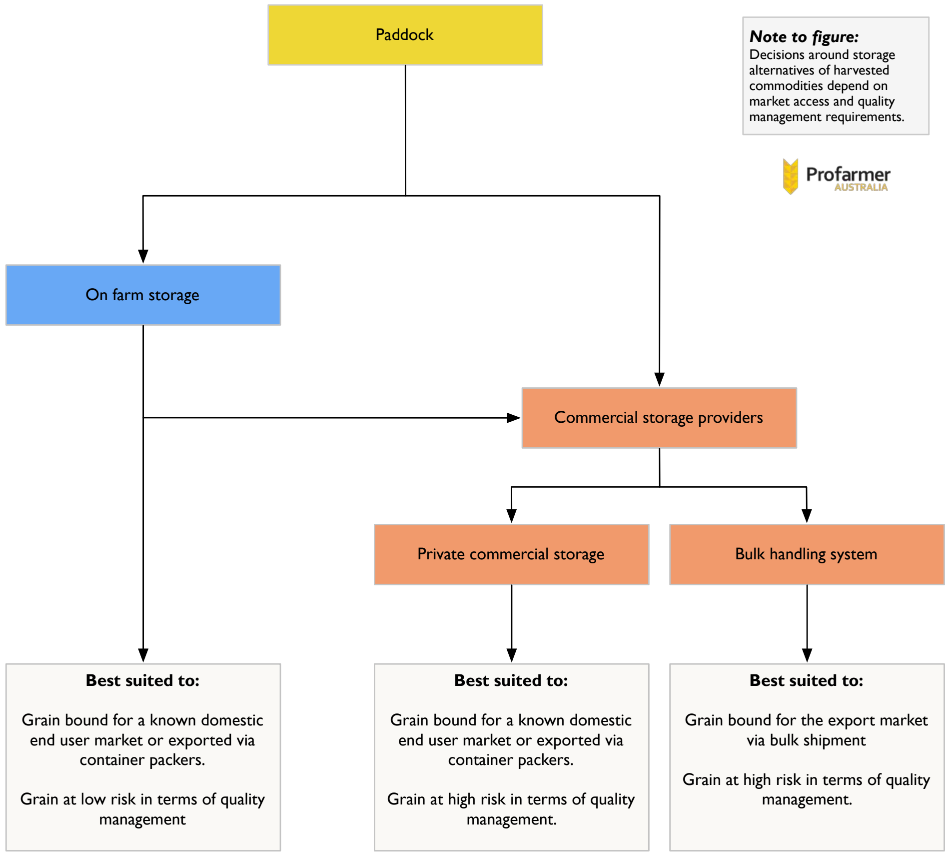


Figure 14: Grain storage decision making.

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.

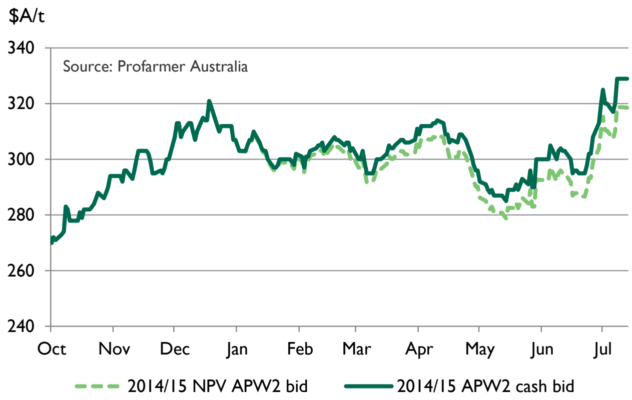
Carry costs are typically $3-4/t per month consisting of:

- monthly storage fee charged by a commercial provider (typically ~$1.50-2.00/t per month)
- the interest associated with having wealth tied up in grain rather than cash or against debt (~$1.50-$2.00/t per month depending on the price of the commodity and interest rates).

The price of carried grain therefore needs to be $3-4/t per month higher than what was offered at harvest.

The cost of carry applies to storing grain on farm as there is a cost of capital invested in the farm storage plus the interest component. $3-4/t per month is a reasonable assumption for on farm storage.

Principle: "Carrying grain is not free" – The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy.



Note to figure:
If selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example in the case of a March sale of APW2 wheat for March-June delivery on buyers call at $300/t + $3/t carry per month, if delivered in June would generate $309/t delivered.

Figure 15: Kwinana APW2 cash vs NPV.

15.1.5 Ensuring market access revised

Optimising farm gate returns involves planning the appropriate storage strategy for each commodity to improve market access and cover carry costs in pricing decisions.

15.1.6 Executing tonnes into cash

This section provides 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
- 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 interest first by not having conflicts of interest and 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 which utilise exchanges such as CBOT can add significant value.

References:

The link below provides current financial members of Grain Trade Australia including buyers, independent information providers, brokers, agents, and banks providing over-the-counter grain derivative products (swaps).

http://www.graintrade.org.au/membership

The link below provides a list of commodity futures brokers.

http://www.asx.com.au/prices/find-a-futures-broker.htm

How to sell for cash

Like any market transaction, a cash grain transaction occurs when a bid by the buyer is matched by an offer from the seller. Cash contracts are made up of the following components with each component requiring a level of risk management:

- Price - Future price is largely unpredictable hence devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.
- Quantity and quality - When entering a cash contract you are committing to delivery of the nominated amount of grain at the quality specified. Hence production and quality risk must be managed.
- Delivery terms - Timing of title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end users it relies on prudent execution management to ensure delivery within the contracted period.
- Payment terms - In Australia the traditional method of contracting requires title of grain to be transferred ahead of payment; hence counterparty risk must be managed.

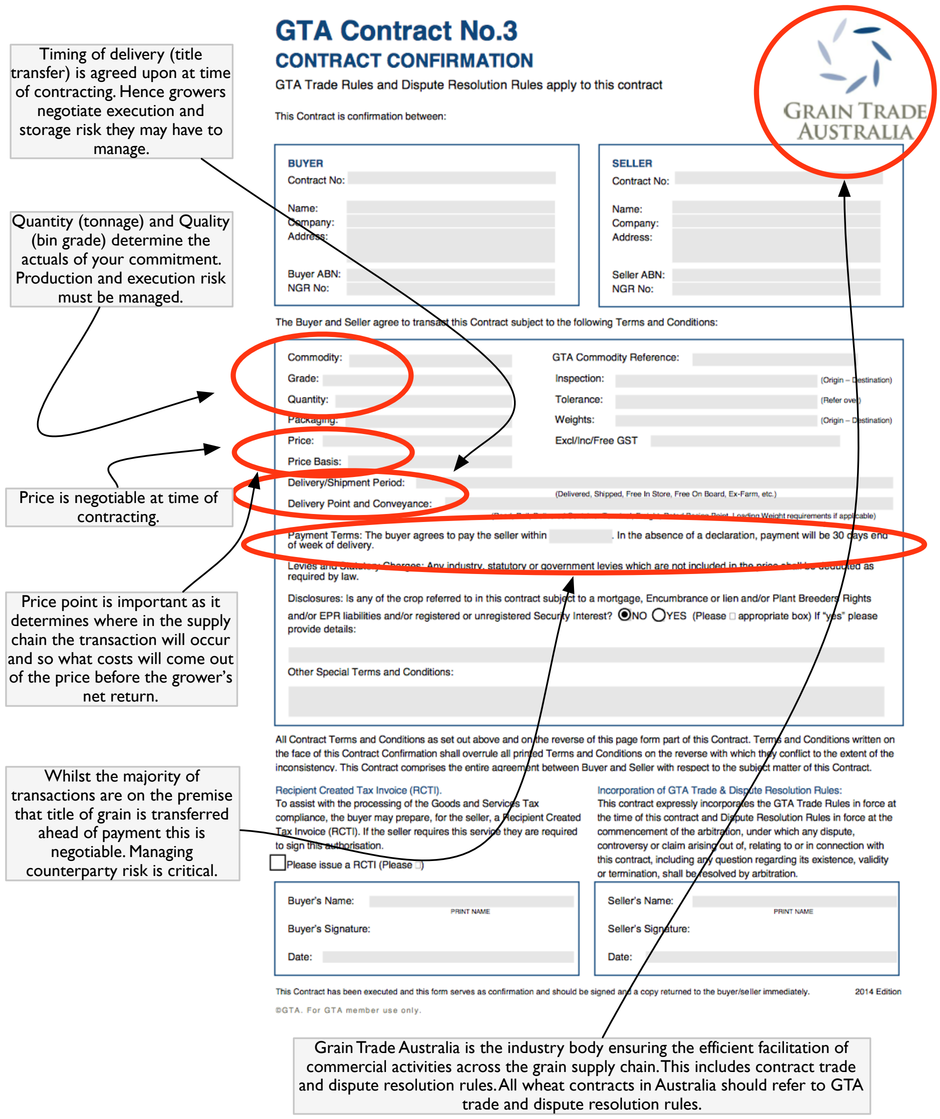


Figure 16: Typical cash contracting.

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. The below image depicts the terminology used to describe pricing points along the grain supply chain and the associated costs to come out of each price before growers receive their net farm gate return.

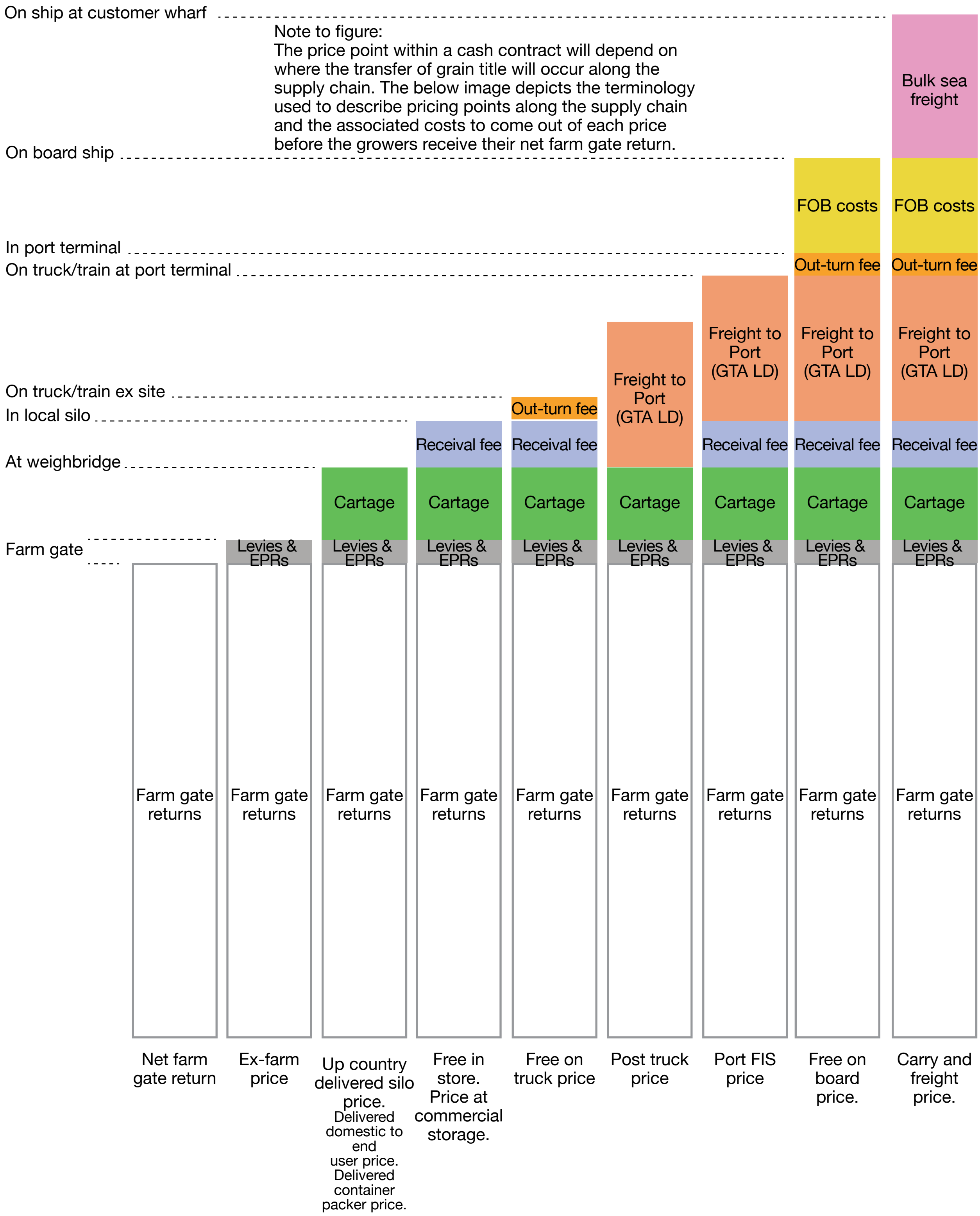


Figure 17: Cost and pricing points throughout the supply chains.

Cash sales generally occur through three methods:

- Negotiation via personal contact - Traditionally prices are posted as a “public indicative bid”. The bid is then accepted or negotiated by a grower with the merchant or via an intermediary. This method is the most common and available for all commodities.
- Accepting a “public firm bid” - Cash prices in the form of public firm bids are posted during harvest and for warehoused grain by merchants on a site basis. Growers can sell their parcel of grain immediately by accepting the price on offer via an online facility and then transfer the grain online to the buyer. The availability of this depends on location and commodity.
- Placing an “anonymous firm offer” - Growers can place a firm offer price on a parcel of grain anonymously and expose it to the entire market of buyers who then bid on it anonymously using the Clear Grain Exchange, which is an independent online exchange. If the firm offer and firm bid match, the parcel transacts via a secure settlement facility where title of grain does not transfer from the grower until funds are received from the buyer. The availability of this depends on location and commodity. Anonymous firm offers can also be placed to buyers by an intermediary acting on behalf of the grower. If the grain sells, the buyer and seller are disclosed to each counterparty.

More information

http://www.australiangrainexport.com.au/docs/Grain Contracts Guide.pdf

http://www.graintrade.org.au/contracts

http://www.graintrade.org.au/commodity standards

http://www.graintransact.com.au

http://www.grainflow.com.au

http://emeraldgrain.com/grower-logins/

https://www.cleargrain.com.au/terms-and-conditions

https://www.cleargrain.com.au/get-started

Counterparty risk

Most sales involve transferring title of grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: “Seller beware” – There is not much point selling for an extra $5/t if you don’t get paid.

Counterparty risk management includes:

- Dealing only with known and trusted counterparties.
- Conduct a credit check (banks will do this) before dealing with a buyer they are unsure of.
- Only sell a small amount of grain to unknown counterparties.
- Consider credit insurance or letter of credit from the buyer.
- Never deliver a second load of grain if payment has not been received for the first.
- Do not part with title of grain before payment or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting, alternatively the Clear Grain Exchange provides secure settlement where-by the grower maintains title of grain until payment is received by the buyer, and then title and payment are settled simultaneously.

More information

GTA managing counterparty risk 14/7/2014

Clear Grain Exchange title transfer model

GrainGrowers Guide to Managing Contract Risk

Counterparty risk: A producer perspective, Leo Delahunty

Above all, act commercially to ensure the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving $5/t more and not getting paid is a disastrous outcome.

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 whilst achieving the business goals of reducing overall risk.

Principle: “Sell valued commodities; not undervalued commodities” – If one commodity is priced strongly relative to another, focus sales there. Don’t sell the cheaper commodity for a discount.

An example based on wheat and barley production system is provided below (Figure 18).

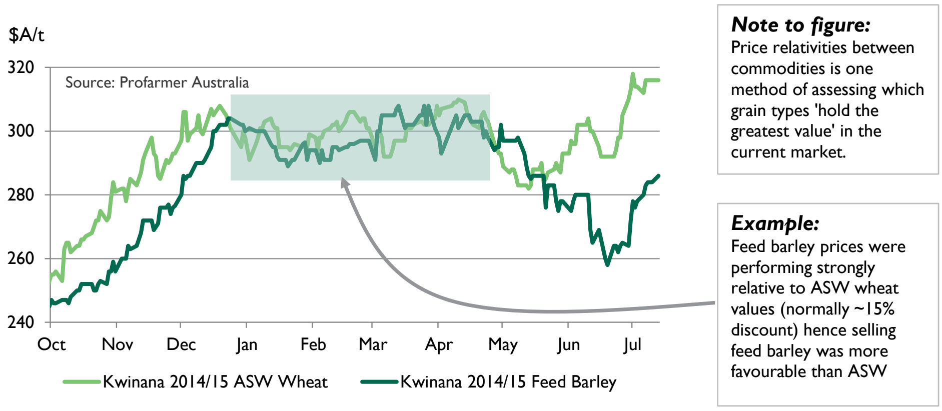


Figure 18: Kwinana ASW wheat vs feed barley.

If the decision has been made to sell wheat, CBOT wheat may be the better alternative if the futures market is showing better value than the cash market.

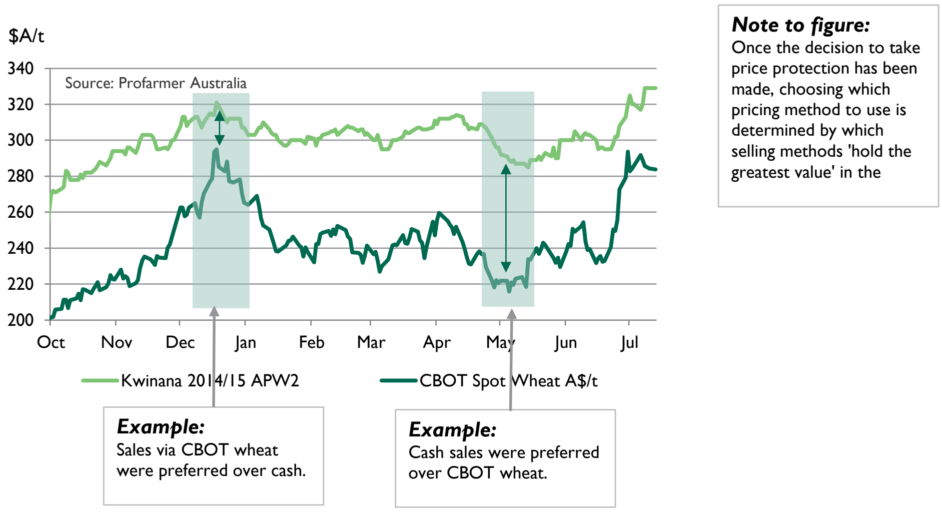


Figure 19: Kwinana APW2 vs CBOT wheat A$/t.

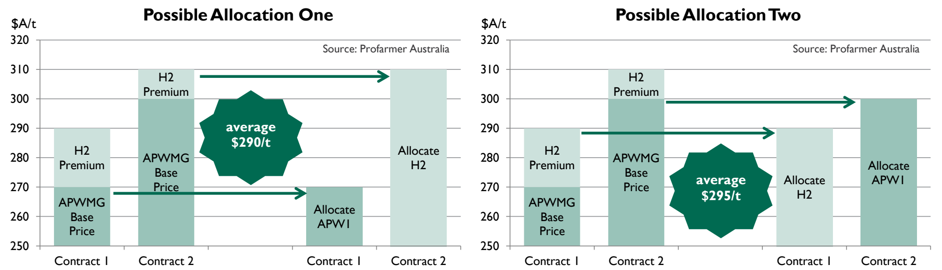
Contract allocation

Contract allocation means choosing which contracts to allocate your grain against come delivery time. Different contracts will have different characteristics (price, premiums-discounts, oil bonuses, etc.), and optimising your allocation reflects immediately on your bottom line.

Principle: “Don’t leave money on the table” - Contract allocation decisions don’t take long, and can be worth thousands of dollars to your bottom line.

To achieve the best average wheat price growers should:

- Allocate your lower grades of wheat to contracts with the lowest discounts.
- Allocate higher grades of wheat to contracts with the highest premiums.



Note to figure:
In these two examples the only difference between acheiving an average price of $290/t and $295/t is which contracts each parcel was allocated to. Over 400/t that equates to $2,000 which could be lost just in how parcels are allocated to contracts.

Figure 20: Possible allocation.

Read market signals

The appetite of buyers to buy a particular commodity will differ over time depending on market circumstances. Ideally growers should aim to sell their commodity when buyer appetite is strong and stand aside from the market when buyers are not that interested in buying the commodity.

Principle: "Sell when there is buyer appetite" – When buyers are chasing grain, growers have more market power to demand a price when selling.

Buyer appetite can be monitored by:

- The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate buyer appetite is strong. However if there is one buyer $5/t above the next best bid, it may mean cash prices are susceptible to falling $5/t if that buyer satisfies their buying appetite.
- Monitoring actual trades against public indicative bids. When trades are occurring above indicative public bids it may indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids.

15.1.7 Sales execution revised

The selling strategy is converted to maximum business revenue by:

- ensuring timely access to information, advice and trading facilities
- using different cash market mechanisms when appropriate
- minimising counterparty risk by effective due diligence
- understanding relative value and selling commodities when they are priced well
- thoughtful contract allocation
- reading market signals to extract value from the market or prevent selling at a discount

15.2 Northern oats – market dynamics and execution

15.2.1 Price determinants for Northern Region oats

The global oat crop is estimated at 20-23Mt each year and Australia is an important player; typically producing 1-1.5Mt annually. Australia exports about 20 per cent of their production each season while the bulk of the crop is consumed domestically. The large majority of exported oats are used for human consumption.

It estimated that Northern Australia produces about 400-500,000t of oats each season. Qld produce only a very small portion of this with the overwhelming majority produced in NSW.

They are primarily influenced by the supply and demand of other local feed sources such as wheat, barley and hay fodder. While the commodities are not necessarily substitutable the price relativity is important in order to ensure consumer supply requirements are met each season.

Although the extensive majority of oats are consumed domestically prices are influenced by relative WA oat values which are tied closely to export values. Northern farm-gate prices are heavily influenced by both local and global factors.

15.2.2 Ensuring market access for Northern oats

Knowing where the Northern Australian oat crop is likely to end-up will help refine a grower's selling and logistics decisions. Understanding whether your grain will be used for milling or feed purposes will help determine the best path to market.

For milling quality oats it is of the upmost importance to maintain grain quality given the discounts in place if the grain fails to meet milling grade standards. Milling oats are often contracted prior to production with consumers looking to lock in supply or alternatively sold into the cash market post-harvest. Given consumers have rigid supply requirements each season forward selling a portion of your crop may offer a premium. It is always important however to manage prospective sales prior to harvesting the crop against your production risk.

Comparatively feed oats are more heavily influenced by domestic factors including the relative price of other feed grains and local feed grain supply and demand fundamentals. There may be further benefit in storing feed grain oats throughout the season and executing sales based on opportunistic pricing. Feed oats are a sought after feed grain due to the low risk nature of the grain and attractive feed characteristics. As a result feed oats can price at strong premiums over other available feed grains.

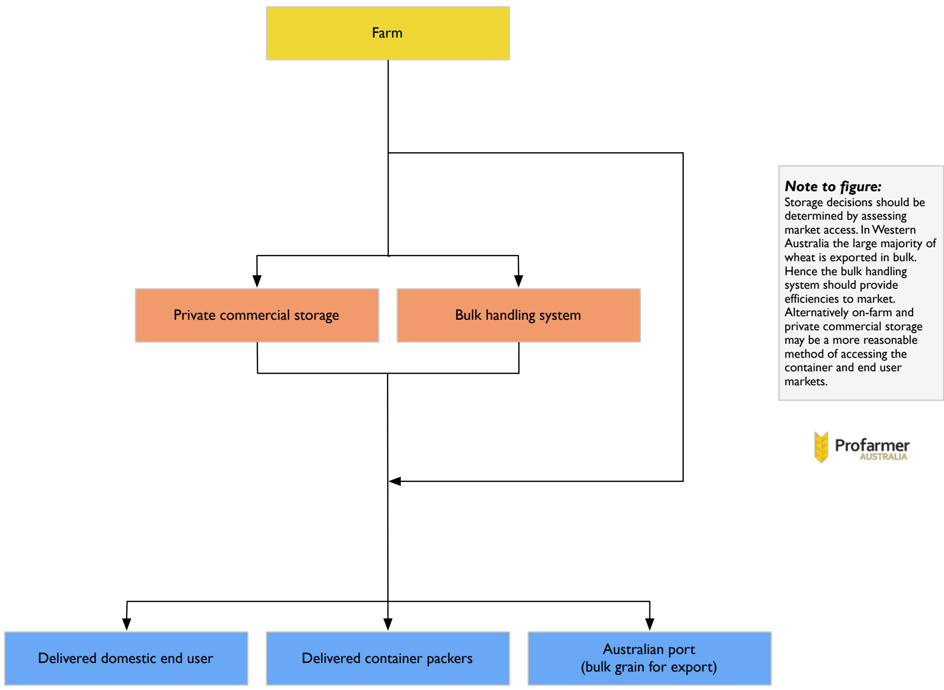


Figure 21: Australian supply chain flow.

15.2.3 Risk management tools available for Northern Region oats

An Australian cash price is made up of three components - futures, foreign exchange, and basis. Each component impacts on price – a higher futures and basis and a lower exchange rate will create a higher Australian grain price.

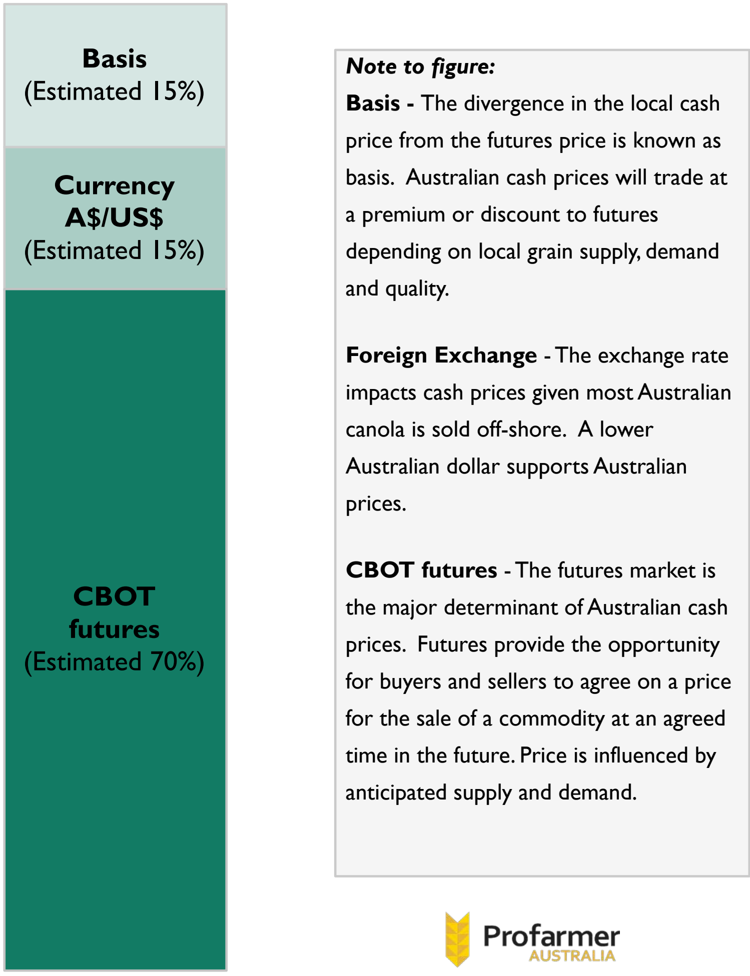


Figure 22: Pricing components.

Table 2: Products available to manage Northern oats prices; the major difference in products is the ability to manage the individual components of price.

	Description	Advantages	Disadvantages
Spot cash contracts	Futures, foreign exchange, basis all locked at time of contracting	Simple to use. Locks in all components of price. Cash is received almost immediately (within payment terms).	Immediate grain delivery required. Sales after harvest require storage which incur costs. Locks away three pricing components at the same time. Risk of counterparty default between transfer and payment.
Forward cash contracts	Futures, foreign exchange, basis all locked at time of contracting	Simple to use. Locks in all components of price (no uncovered price risk). No storage costs. Cash income is a known ahead of harvest	Often inflexible and difficult to exit. Locks away the three pricing components at the same time. Future delivery is required resulting in production risk. Counterparty default risk must be managed.
Futures contracts	Futures, foreign exchange, basis are able to be managed individually	Liquid markets enable easy entry and exit from the marketplace. Locks in only some components of price, hence more flexible than cash contracts. Price determined by the market, and is completely transparent. No counterparty risk due to daily clearing of the contracts.	Requires constant management and monitoring. Margin calls occur with market movements creating cash-flow implications. Grain is required to offset the futures position, hence production risk exists. Cash prices may not move inline with futures, hence some price risk. You still have to sell the underlying physical grain.
Over-the-counter bank swaps on futures contracts	Futures, foreign exchange, basis are able to be managed individually	Based off an underlying futures market so reasonable price transparency. Liquid markets enable easy entry and exit from the marketplace. Locks in only some components of price, hence more flexible than cash contracts. Counter party risk is with the bank, hence it is low. The bank will manage some of the complexity on behalf of the grower, including day to day margin calls.	Costs vary between $5-10/t at the providers discretion. Requires constant management and monitoring. Grain is required to offset the futures position, hence production risk exists. Cash prices may not move inline with futures, hence some price risk. You still have to sell the underlying physical grain.
Options on futures contracts	Futures, foreign exchange, basis are able to be managed individually	No counterparty risk due to daily clearing of the contracts. No margin calls. Protects against negative price moves but can provide some exposure to positive moves if they eventuate. Liquid markets enable easy entry and exit from the marketplace. Price risk can be reduced without increasing production risk. Price determined by the market, and is completely transparent.	Options can be costly and require payment upfront. The value of options erode overtime as expiry approaches - depreciating asset. Perceived to be complicated by growers. Move in option value may not completely offset move in cash markets. You still have to sell the underlying physical grain.

More information

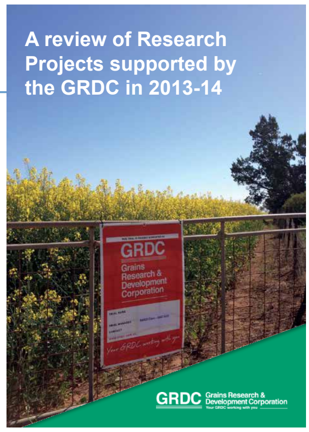
For more information and worked examples on how each pricing component affects wheat grain price refer to the GRDC publication Grain Market Lingo – what does it all mean?

www.grdc.com.au/GrainMarketLingo

SECTION 16

Current research

Project Summaries of GRDC-supported projects in 2013-14



Each year the GRDC supports several hundred research and development, and capacity building projects.

In the interests of improving awareness of these investments among growers, advisers and other stakeholders, the GRDC has assembled summaries of projects active in 2013-14.

These summaries are written by our research partners as part of the Project Specification for each project, and are intended to communicate a useful summary of the research activities for each project investment.

The review expands our existing communication products where we summarise the R&D portfolio in publications such as the Five-year Strategic Research and Development Plan, the Annual Operating Plan, the Annual Report and the Growers Report.

GRDC's project portfolio is dynamic with projects concluding and new projects commencing on a regular basis. Project Summaries are proposed to become a regular publication, available to everyone from the GRDC website.

Projects are assembled by GRDC R&D investment Theme area, as shown in the PDF documents available. For each Theme a Table of Contents of what is contained in the full PDF is also provided, so users can see a list of project titles that are covered. The GRDC investment Theme areas are:

- Meeting market requirements;
- Improving crop yield;
- Protecting your crop;
- Advancing profitable farming systems;
- Maintaining the resource base; and
- Building skills and capacity.

The GRDC values the input and feedback it receives from its stakeholders and so would welcome your feedback on any aspect of this first review. This way we can continue to improve and extend this summary.

To send us your feedback please email us at feedback@grdc.com.au

SECTION 17

Key contacts

James Clark - Chair

James Clark lives in the NSW Hunter Valley and brings to the panel his extensive experience in both dryland and irrigated farming in the North Star area of northern NSW. James has served as a panellist since 2005 and chair since 2008. He says the role of the panel is to capture growers' priorities, realise them into a pipeline of investments and empower growers to take up production gain opportunities as they arise. He believes the grains industry needs to continue to build future RD&E capacity and capability to service its needs going forward and ensure growers remain as competitive as possible.

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Loretta Serafin

Loretta Serafin has extensive experience as an agronomist in northwest NSW and works with the NSW Department of Primary Industries in Tamworth. As the leader northern dryland cropping systems, she provides expertise and support to growers, industry and agronomists in the production of summer crops. Loretta is a member of numerous industry bodies and has a passion for helping growers improve farm efficiency. She sees her role as a conduit between advisers, growers and the GRDC to ensure growers' research needs are being met.

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Jules Dixon

Jules Dixon has an extensive background in agronomy and an established network spanning eastern Australia and WA including researchers, leading growers and agronomy consultants through to the multinational privatesector. Based in Sydney, Jules operates a private consultancy specialising in agronomy, strategy development and business review.

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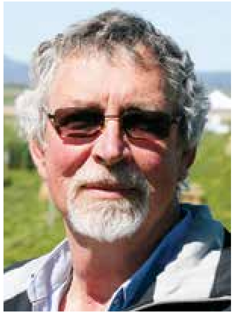
Neil Fettell



Neil Fettell is a part-time senior research adviser with Central West Farming Systems and runs a small irrigation farm near Condobolin, NSW. Neil has a research agronomy background, conducting field research in variety improvement, crop physiology and nutrition, water use efficiency and farming systems. He is a passionate supporter of research that delivers productivity gains to growers, and of grower participation in setting research goals.

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Penny Heuston

Penny Heuston is an agronomist based in Warren, NSW. She is passionate about the survival of the family farm and its role in the health of local economies. Penny is dedicated to ensuring research is practical, farm-ready and based on sound science and rigor. She sees 'two-way communication' as one of the panellists' primary roles and is committed to bringing issues from the paddock to 'the lab' and conversely, the science to the paddock.

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Andrew McFadyen

Andrew McFadyen is an agronomist and manager with Paspaley Pastoral Company near Coolah, NSW, with more than 15years' agronomy and practical farm management experience. He is an active member of the grains industry with former roles on the Central East Research Advisory Committee, NSW Farmers Coolah branch and planning committees for GRDC Updates. He is also a board member and the chair of Grain Orana Alliance.

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John Minogue

John Minogue runs a mixed broadacre farming business and an agricultural consultancy, Agriculture and General Consulting, at Barmedman in south-west NSW. John is chair of the district council of the NSW Farmers' Association, sits on the grains committee of the NSW Farmers' Association and is a winner of the Central West Conservation Farmer of the Year award. His vast agricultural experience in centralwest NSW has given him a valuable insight into the long-term grains industry challenges.

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Jack Williamson

Jack Williamson is a private agricultural consultant and helps run a family broadacre farm near Goondiwindi, Queensland. Six years of retail agronomy and three years of chemical sales management have given Jack extensive farming systems knowledge, and diverse crop management and field work experience. He is a member of the Northern Grower Alliance local consultative committee and Crop Consultants Australia.

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Arthur Gearon

Arthur Gearon is a grain, cotton and beef producer located near Chinchilla, Queensland. He has a business degree from the Queensland University of Technology in international business and management and has completed the Australian Institute of Company Directors course. He is vice-president of AgForce Grains and has an extensive industry network throughout Queensland. Arthur believes technology and the ability to apply it across industry will be the key driver for economic growth in the grains industry.
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Dr Tony Hamilton

Tony Hamilton is a grower from Forbes, NSW, and managing director of an integrated cropping and livestock business. He is a member of GRDC's Regional Cropping Solutions Network – Irrigation panel and a director of the Rural Industries Research and Development Corporation. He has worked as an agricultural consultant in WA and southern NSW. With a Bachelor of Agricultural Science and a PhD in agronomy, Tony advocates agricultural RD&E and evidence-based agriculture.
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Brondwen MacLean

Brondwen MacLean was appointed to the Northern Panel in August 2015 and is the GRDC executive manager for research programs. She has primary accountability for managing all aspects of the GRDC's nationally coordinated R&D investment portfolio and aims to ensure that these investments generate the best possible return for Australian grain growers. Prior to her current appointment, Brondwen was senior manager, breeding programs, and theme coordinator for Theme 6, Building Skills and Capacity.
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David Lord - Panel Support Officer

David Lord operates Lord Ag Consulting, an agricultural consultancy service. Previously, David worked as a project officer for Independent Consultants Australia Network, which gave him a good understanding of the issues growers are facing in the northern grains region. David is the Northern Panel and Regional Grower Services support officer.
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SECTION 18

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